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MAY 78 A P MEYER, J A BETT, R A SEDERQUIST DAAK70-77-C-0195

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# PARAMETRIC ANALYSES OF 1.5-KW METHANOL FUEL CELL POWER PLANT DESIGNS

Final Technical Report

19 May 1978

by
A.P. Meyer
J.A.S. Bett
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Prepared for

U.S. Army Mobility Equipment
Research and Development Command
Fort Belvoir, Virginia

Contract No. DAAK70-77-C-0195





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ABSTRACT

In recent years, spurred by the changing availability of petroleum fuels, the Army has begun to investigate the use of alternative fuels such as methanol. Under its SLEEP (Silent Lightweight Electric Energy Plants) program, MERADCOM has sponsored a design investigation to determine the viability of a methanol-fueled 1.5-kW fuel cell power plant for field service. The design is based on a low-temperature reformer and a commercial phosphoric-acid-technology fuel cell stack. Comparison of predicted power plant characteristics with goal Purchase Description Requirements shows that the concept has sufficient potential to be pursued further. Experimental work shows commercial-methanol fuels containing higher alcohols may be suitable fuels for this power plant. Additional experimental work and system analysis are needed to finalize reformer and power plant operating conditions and characteristics.

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## SUMMARY

The objective of this program was to determine whether the low-temperature reforming process and a commercial technology fuel cell stack were a viable basis for the design of a 1.5-kW fuel cell power plant for Army field service. Two power plant concepts were evaluated: one fueled with a premixed methanol-water fuel and the second fueled with methanol only. The second concept incorporates a water-recovery system that condenses water from the power plant exhaust and supplies it to the fuel processor for the reforming reaction.

Preliminary system designs were prepared and preliminary power plant characteristics were defined. An artist's rendering of the premix power plant is shown in Figure 1. Nine key parameters selected from the Army's goal Purchase Description Requirement were used as the criteria against which to evaluate the power plants. These parameters and the characteristics of the premix power plant are presented below. The design satisfies all requirements but weight and volume. However, the power plant's fuel consumption is 40 percent better than required. A tradeoff can be effected between fuel consumption and power plant weight and volume. A preliminary estimate shows

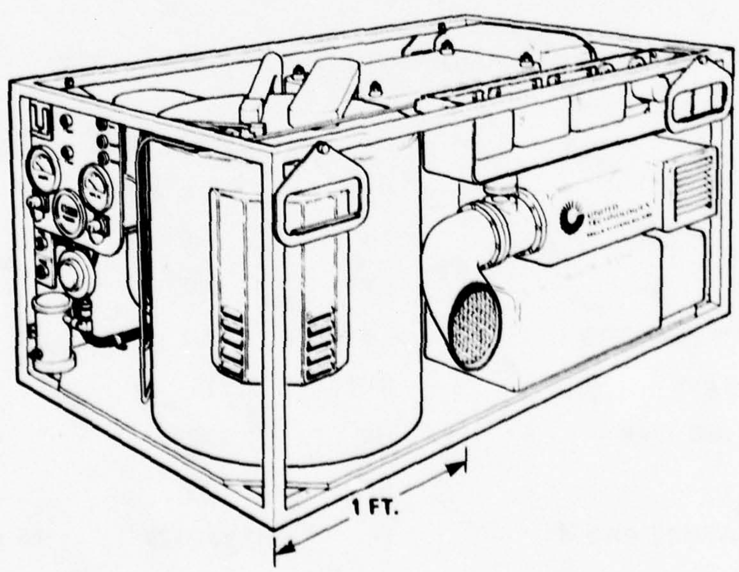


Figure 1. Preliminary 1.5-kW Methanol Fuel Cell Power Plant Design

that by increasing fuel consumption 14 percent for the dc power plant, the weight and volume goals can be satisfied. This design is considered a viable basis for power plant development and should be studied further.

The power plant with water recovery is 48 percent heavier and 16 percent greater in volume than the premix fuel power plant. Because of the increased weight and volume, decreased MTBF, higher development cost due to system complexity, and the problem of freeze protection in the water recovery system, this design is not recommended for additional study.

A major portion of the program was devoted to investigating the low-temperature reforming of methanol and the effect on the reaction of higher alcohols contained in the methanol. The results indicate that some higher alcohols, such as ethanol and isobutanol, can be permitted in the fuel if reforming temperature is raised. The temperature increase is within the low-temperature reforming regime. Additional work, however, is required to confirm that increasing the temperature has no adverse effect on catalyst life or activity over long operating periods. The effects on the fuel cell of reaction products of higher alcohols or unreacted higher alcohols that pass through to the cell stack must also be determined to verify the suitability of operating on low-purity methanols.

MODE IV POWER PLANT CHARACTERISTICS, DC SET: PREMIX FUEL

| | | REQUIREMENT | DESIGN |
|---|---|---|---|
| RATED OUTPUT | KW | 1.5 | 1.5 |
| WEIGHT | LB | 150 | 175 |
| VOLUME | $FT^3$ | 6.0 | 7 |
| FUEL CONSUMPTION | LB/KWHR | 2.2 | 1.22 |
| START TIME | MIN | 15 | 15 |
| OPERATING LIFE | HR | 6000 | 6000 |
| MTBF | HR | 750 | 1500 |
| TEMPERATURE RANGE | °F | -65 to +125 | -65 to +125 |
| NO. OF STARTS | | 2000 | 2000 |

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# PREFACE

This final technical report was prepared by the Power Systems Division of United Technologies Corporation and is submitted as part of the contractual requirements of U.S. Army Mobility Equipment Research and Development Command Contract DAAK70-77-C-0195.

The technical work presented in this final report was performed during the period between September 1977 and March 1978.

Messieurs R. N. Belt, W. G. Taschek, and S. S. Kurpit of the U. S. Army Mobility Equipment Research and Development Command provided valuable assistance in carrying out this work.

Messieurs A. P. Meyer, R. A. Sederquist, J. A. S. Bett, G. Vartanian, D. Szydlowski, and S. Karavolis of Power Systems Division participated in the program and the preparation of this report.

# INTRODUCTION

The U. S. Army is engaged in fuel cell programs directed primarily at developing a family of Silent Lightweight Electric Energy Plants (SLEEP) with output ratings of 0.5 to 5.0 kW. Originally, only logistic fuels were considered under this program, but the changing availability in recent years of traditional petroleum-based fuels has prompted serious consideration of alternative fuels. In 1973, MERADCOM demonstrated a methanol-fueled 1.5-kW power plant based on a low-temperature steam reformer and a phosphoric-acid stack.[1] The success of this work led to Contract DAAK 70-77-C-0195 to assess the potential of this power plant concept for development to Army field service requirements.

The assessment considered two power plant concepts, one fueled with a premix of methanol and water and a second fueled with methanol only. The latter incorporates a system for recovering water from the power plant exhaust for the reforming process. The potential of both concepts for field development was assessed by defining their characteristics in a conceptual design study and comparing those characteristics with nine key parameters selected from the Army's goal Purchase Description Requirement for a 1.5-kW fuel cell power plant.

The power plant design was based on the low-temperature reforming process and commercial fuel cell power plant technology for the cell stack and ancillaries wherever possible. Power conditioner characteristics were based on units developed for MERADCOM under previous contracts. This approach was chosen because it minimizes the development work the Army must sponsor and reduces the cost of bringing fuel cells into military ground power service: only the technology which is unique to Army requirements, i.e., a methanol reformer, need be developed by the Army alone.

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1. S. S. Kurpit, U.S. Army, MERADCOM, IECEC Record (1975), "1.5- and 3-kW Indirect Methanol-Air Fuel Cell Power Plants."

The program was carried out in three major subtasks: 1.0, Data Base Review; 2.0, Data Base Confirmation Testing; and 3.0, Conceptual Definition of Power Plant Systems. Under Subtask 1.0, a technology base was established for the fuel cell stack, the control system, the power conditioners, and the fuel processor. Because the low-temperature reforming process data available had in greatest part been based on reagent-grade methanols, the second subtask, 2.0, was undertaken. This work defined the effects on the reforming process of higher alcohols and impurities in the feed stock. Higher alcohols and other impurities are found in many commercial sources of methanol. Higher alcohols do not reform as completely as methanol, so the effect of higher alcohol carry-over from the reformer into the fuel cell was investigated in laboratory tests. Using the data base established under these two subtasks, a conceptual design for a 1.5-kW premix-fuel power plant was defined and its characteristics were established in Subtask 3.0. Under Subtask 3.0, the design and characteristics of the power plant with water recovery were also defined.

# INVESTIGATION AND DISCUSSION

## SUBTASK 1.0, DATA BASE REVIEW

### A. Low-Temperature Reformer Technology

Several variable parameters of catalyst behavior have to be defined for use in the fuel processor design calculations. First, an expression is required for the rate of conversion of methanol over the range of operating temperatures and feed compositions. Since it is common in practice for the activity of a catalyst to decrease with time due to the cumulative effects of a variety of chemical and physical phenomena, a rate of degradation must be estimated in order that the reactor can be designed to meet rated power requirements at the end of its projected lifetime. Two treatments of this problem are possible. The cumulative rate of decay in activity can be measured at close to operating conditions and the end-of-life activity estimated by extrapolation. Alternatively, the contribution of individual phenomena to the overall decrease in activity can be evaluated separately and factored into the basic expression for initial catalyst activity to generate an end-of-life value. The more flexible second approach has been employed in this study.

The degradation phenomena evaluated included the following: the decrease in activity due to thermal sintering and loss of surface area of the catalyst, the degradation of the catalyst due to carbon formation at low steam to carbon ratios in the feed gas, and the decrease in activity due to sulfur and chlorine impurities in the feed. These effects were determined in experiments using high-purity, reagent-grade methanol. The effects of higher alcohols as impurities in the methanol were also evaluated in order to permit consideration of commercial alcohols as reactor feed.

Design calculations for the fuel processor employed reactor conversion computations that included heat- and mass-transfer considerations within the catalyst bed and an expression for the intrinsic activity of the catalyst for steam reforming methanol. Although the true functional dependence of the rate on

steam and methanol pressures was obviously complex, as will be seen in the data presentation, a simple treatment, pseudo-first-order in methanol, was deemed adequate for reactor design since a similar treatment had given satisfactory results for low-temperature reforming of hydrocarbon feeds.

Not included in program plans was an optimization of catalyst activity. The decision was made, considering limitations of time, to use available data to select the best commercial catalyst for evaluation, rather than to screen the performance of a number of catalysts. No systematic study of catalyst activity for methanol steam reforming has been reported other than that of Leesona Moos Laboratories,[1] in which a variety of cobalt, iron, nickel, and copper-containing catalysts was examined and a copper zinc-oxide catalyst from Girdler Catalyst Company was selected as optimum. A number of studies of related copper zinc oxide catalysts confirm this activity, [2] [3] and therefore we selected for evaluation a similar copper zinc-oxide catalyst recommended by the United Catalyst Corporation (formerly Girdler).

Some data had been previously reported for the activity of similar copper zinc-oxide catalysts in methanol steam reforming. The data were collated in Figure 2, where in each case a simple pseudo-first-order treatment was applied for comparison. Considering the spread in time between studies, which will introduce variation in catalyst formulation, and variation in source of methanol, the first-order rate constants were in reasonable agreement. In each of the reports, some consideration was made of catalyst degradation, but this was generally an evaluation of the cumulative effect of a specific methanol feed and reactor condition. In this work, therefore, we chose to determine a baseline activity for the catalyst T2130, manufactured by United Catalysts, Inc., operating on a laboratory reagent-grade methanol and to subsequently estimate the effects of individual modes of deactivation.

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1. N.I. Palmer, Leesona Moos Laboratories, Project 7255, SR-65-7255, August 4, 1965.
2. F. L. Kester, A. J. Konopka, and E. Camara, Institute of Gas Technology, USEPA, Office of the Air and Water Programs, Contract 68-03-2057, November 1975.
3. Army Mobility Equipment R&D Center, Fort Belvoir, Virginia. Private communication.
4. UTC commercial program data.

## B. Fuel Cell Technology

The design of the power plant's fuel cell stack is based on the cells that PSD is developing for commercial application in the 1980's. This work is being sponsored by the DOE, EPRI, and PSD for both large megawatt-scale electric utility power plants and on-site power plants with outputs in the range of 40 to 250 kW.

Figure 3 shows the cell performance curves used for this study. An initial performance line, a 6000-hour performance line without a 2000-start degradation allowance, and a 6000-hour performance line with a degradation allowance for 2000 starts are shown. The first two lines are based on tests of subscale cells (2 x 2 in.) of the commercial configuration under development for 1980's application. The test data is shown in Figure 4 with the baseline used for development of the curves in Figure 3. The baseline data is for cell operation at 375°F and 200 amperes per square foot. For this design, operating temperature was reduced to 350°F to reduce the loss of acid into the cathode airstream. The maximum design current density is less than 150 ASF,

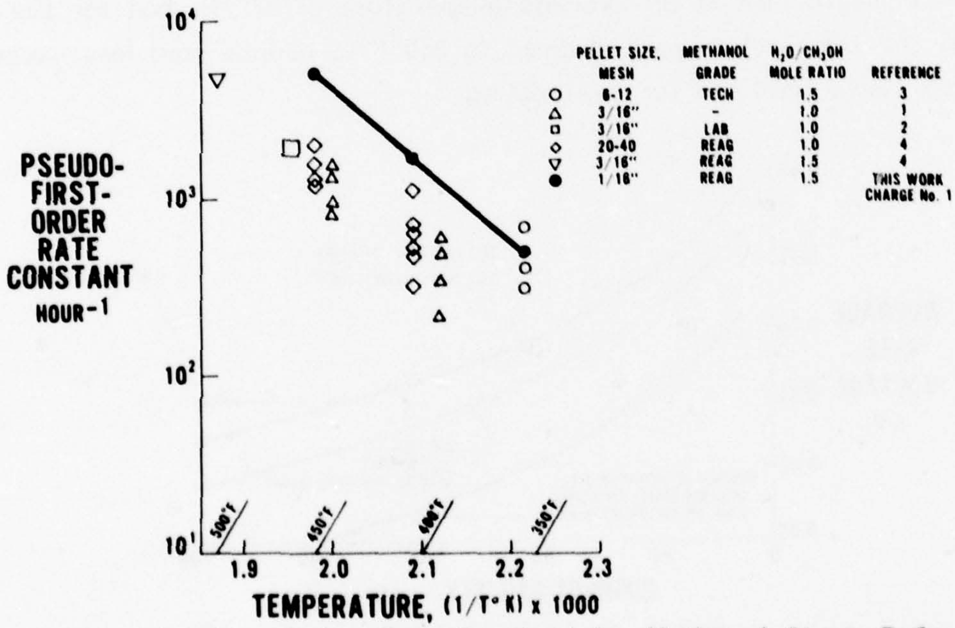


Figure 2. Pseudo-First-Order Rate Constant for Methanol Steam Reforming on Copper Zinc-Oxide Catalysts

well under commercial power plant design and experience levels. The conversion of the baseline data to the power plant design performance was carried out using an analytical method verified by test experience. The third line includes a degradation allowance for 2000 starts because the Army's weight, volume, and start-time requirements preclude the use of the protective systems used in commercial power plants to circumvent these losses.

The added degradation is an estimate calculated from PSD's semi-empirical correlation of startup and shutdown conditions, i.e., temperature and operating potential, and their effects on performance. To be conservative, we doubled the calculated value and then subtracted it from the upper 6000-hour performance curve to define the lower line. PSD recommends that verification of startup and shutdown losses over thousands of starts be included in a future program if development of this power plant is pursued.

The electrochemical portion of the cell consists of an anode, cathode, and matrix. The anode and cathode are fabricated of carbon fiber paper with submilligram catalyst loadings. The matrix consists of an inorganic particulate layer filled with phosphoric acid. In most of PSD's commercial power plants, the cells are maintained at an average temperature of 375°F, but for the Army application the temperature was lowered to 350°F to reduce acid loss caused by the high air flows required for cell cooling.

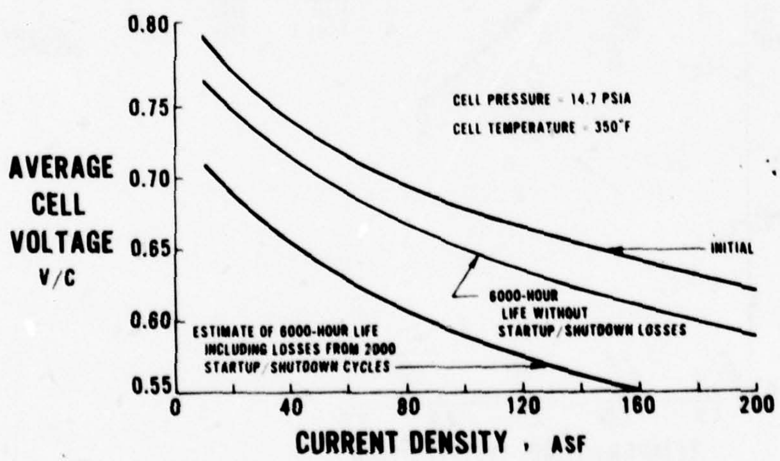


Figure 3. Cell Performance

C. Power Conditioner Technology

INVERTER. The inverter characteristics used in the conceptual design of the Mode III set are based on an inverter developed by Delta Electronic Control Corporation of Irvine, California. The data used in this design study is contained in a report by Dietrich J. Roesler (U. S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia) and Larry R. Suelzle (Delta Electronic Control Corporation, Irvine, California), and is summarized in Table 1.

TABLE 1. DESIGN STUDY SUMMARY

| | |
|---|---|
| Power | 1.5 kW |
| Efficiency | 81 to 86% |
| Voltage (input) | 36 to 60 Vdc |
| Weight | 54 lb |
| Volume | 1517 in$^3$ |
| Tare Power | 60 watts (logic and blower) |

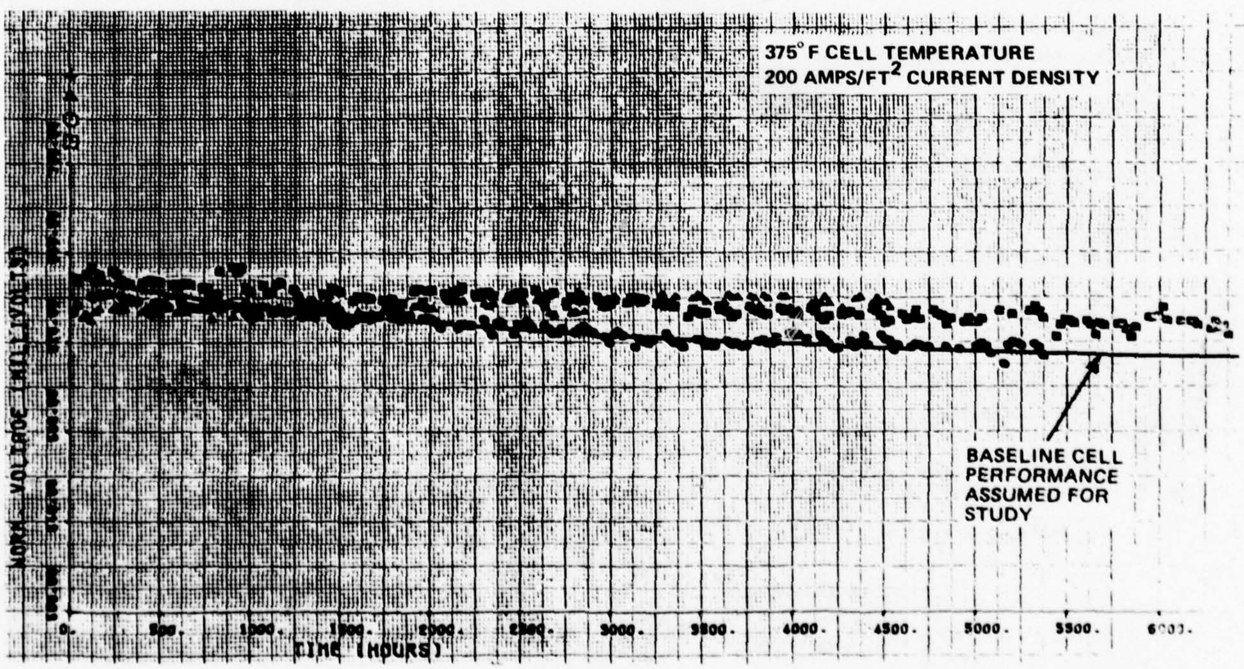


Figure 4. Three Cells Meeting Performance Goal

DC VOLTAGE REGULATOR. The PC14 dc voltage regulator was selected for the power conditioner in the Mode IV set conceptual design. This dc regulator was developed by Engineered Magnetics, Inc., of Hawthorne, California and was incorporated into the four PC14 1.5-kW power plants supplied to USAMERADCOM under Contract DAAK02-70-C-0518. Although there have been advances in integrated circuit and transistor technologies, since this design was established, they are judged to have no significant impact on the power plant's primary characteristics. A comparison of the purchase description requirements with demonstrated PC14 voltage regulator performance in Table 2 shows that the regulator meets or exceeds all requirements except the output voltage adjustment range. Modification to achieve compliance with the Purchase Description in this area will not significantly affect the regulator or power plant characteristics. The primary characteristics of the voltage regulator are shown in Table 3.

TABLE 2. VOLTAGE REGULATOR PERFORMANCE

| | Purchase Description Requirements | PC14 Voltage Regulator Performance |
|---|---|---|
| Power | 1.5 kW | 1.5 kW |
| Voltage Adjustment | 23 to 35 volts | 26 to 34 volts |
| Voltage Regulation | 3% of 28 volts | 2.4% of 28 volts |
| Steady-State Stability | 2% of rated voltage @ all constant loads | 2% of rated voltage @ all constant loads |
| Voltage Ripple | 5.5% peak to peak | 1.1% peak to peak |
| Voltage Drift | 5% of rated value | 5% of rated value |
| Transient Voltage Performance | 30% dip from no load to rated load, 40% rise from rated load to no load | 30% dip from no load to rated load, 40% rise from rated load to no load |

TABLE 3. VOLTAGE REGULATOR PRIMARY CHARACTERISTICS

| | |
|---|---|
| Efficiency | 91% |
| Weight | 14 lb |
| Volume | 660 $in^3$ |

## SUBTASK 2.0, DATA BASE CONFIRMATION TESTING

### A. Low-Temperature Reformer Investigation

EXPERIMENTAL PROGRAM OBJECTIVE. The experimental program objective was to provide a data base for design of the methanol steam-reforming reactor. The first task was to obtain data necessary to design the reactor for operation with reagent-grade methanol. Catalyst activities were determined for operation of the power plant at rated power and for changes in performance expected from operation at off-rated conditions of temperature, pressure, and feed composition. These data defined the baseline catalyst activity. The second task was to measure the effect on steam-reforming activity of impurities expected to be present in commercial grades of methanol. Performance penalties resulting from various levels of contamination could then be estimated and factored into the baseline activity so that the reactor could be designed to achieve rated power with the end-of-life catalyst activity.

EXPERIMENTAL DETAILS. The experimental details of the program to provide a data base for design of the methanol steam-reforming reactor are given in the following paragraphs on apparatus, catalyst, methanol, and experimental procedure.

Apparatus. Catalyst activity and the effects of operating parameter variation were determined in a packed-bed flow reactor. Diagrams of the reactor and test stand appear in Figures 5 and 6. The premixed reactant was pumped into an electrically heated boiler by a Milton Roy variable-speed reciprocating pump. The boiler, a tube 0.75 inch in diameter, 24 inches long, and filled with 1/8-inch stainless steel shot, vaporized the reactants into the reactor. The reactor was a tube 0.75 inches in diameter (0.65 inch i.d.) and 24 inches long, heated by five separately controlled resistance heaters. Provision was made for reading the temperatures by thermocouples placed in the axis of the tube and at the exterior wall. Temperature differences between the two positions were never more than 5°F. The catalyst was loaded in three sections of

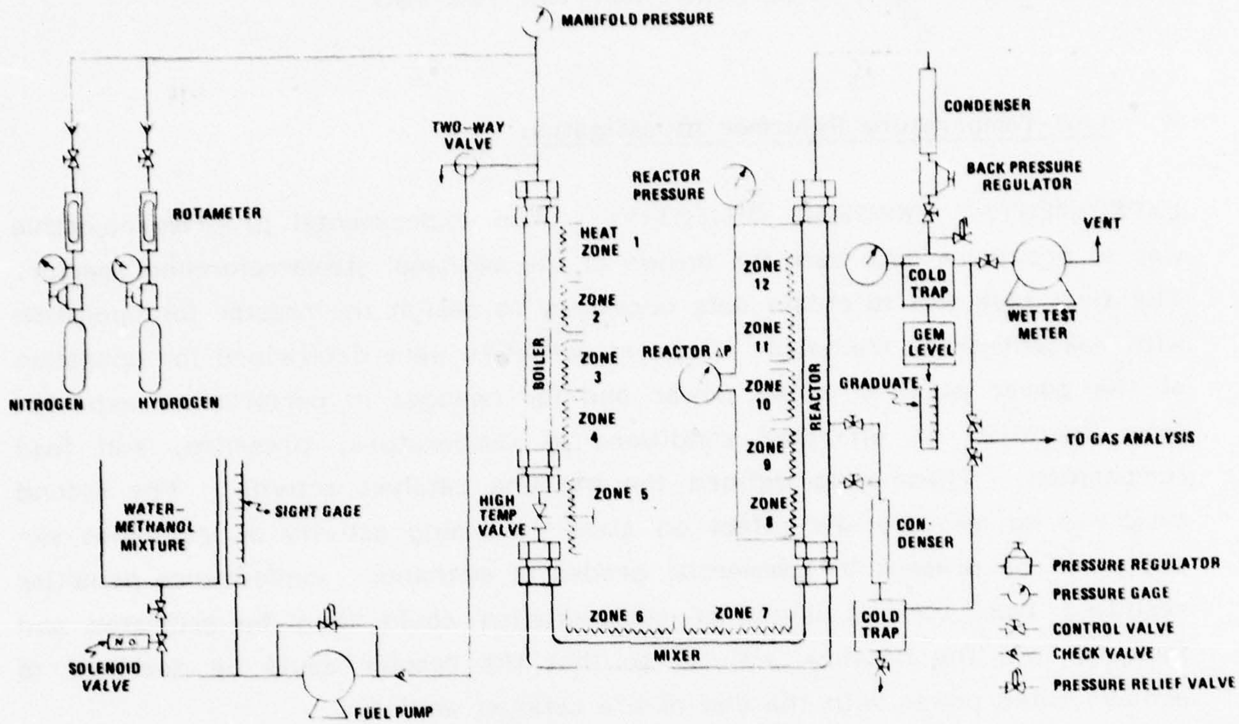


Figure 5. Methanol Steam Reforming Rig

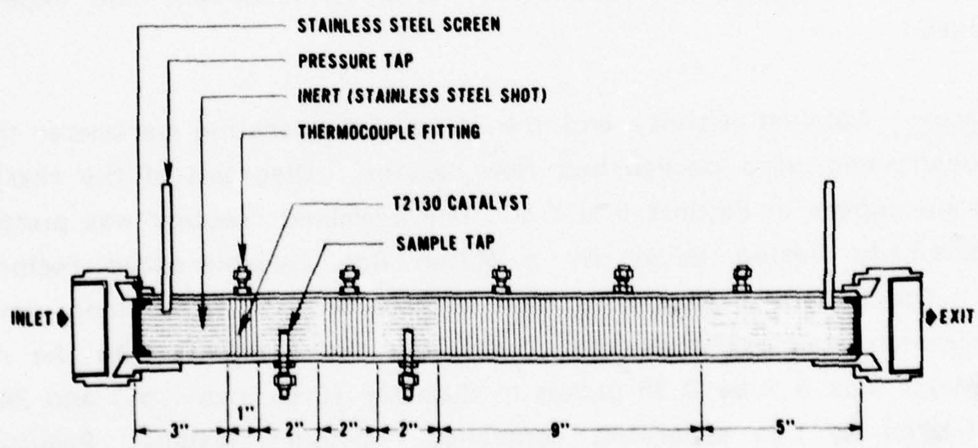


Figure 6. Methanol Steam Reforming Reactor

1 inch, 2 inches, and 9 inches, separated by stainless steel shot. At first, analyses of reaction products were taken at the reactor exit and between the three catalyst sections to give conversions simultaneously at two space velocities, but early experiments showed that it was not possible to withdraw samples from taps without disrupting the reactant flow. Consequently, only the exit sample tap was used in the experiments reported here. Experiments with 99 and 25 g of catalyst in the reactor gave the same intrinsic activity for the catalyst, indicating that no significant blank activity resulted from inclusion of the stainless steel shot.

The effluent gas from the reactor passed through a pressure-regulating valve, enabling the system to be operated above atmospheric pressure when desired; then the gas entered a condenser tube and liquid condensate trap operated at 40°F. The rate of gas evolution was measured with a wet test meter on the effluent from the liquid condensate trap. Some methanol vapor passed through this trap, but by the inclusion of an additional condensing coil in an ice-bath, the amount of methanol vapor was shown to be insufficient to affect the wet test meter reading. The dry gas flow could be diverted for analysis by gas chromatography. Both CO and $CO_2$ were determined by non dispersive infrared detector. Hydrocarbon gases could be determined by flame ionization detector, but they were always insignificant in quantity. Leaks in the reactor system would admit $N_2$, but this was shown to be absent by thermal conductivity detector. The volumetric flow rate of CO, $CO_2$, and (by difference) $H_2$ were therefore calculated from the total dry gas flow rate. The conversion of methanol was calculated from the rate of hydrogen evolution, based on stoichiometric conversion to carbon dioxide:

$$CH_3OH + H_2O \rightarrow CO_2 + 3\ H_2 \qquad (1)$$

Since the ratio of CO to $CO_2$ produced was always less than 0.02, this did not introduce significant error. The conversion could also be calculated independently from the quantity of water condensate from the reactor. As shown in Figure 7, the two methods were in good agreement.

In addition to the liquid reactant pump, provision was made for dry hydrogen and nitrogen flow through the reactor, used in reduction procedures. There was also an independent supply of pure water vapor to the reactor, although this was not used in this present experimental sequence.

The reactor was assembled in a test-stand facility with provision for some automated operation. Temperatures and pressures in critical sections of the apparatus were monitored and would initiate automatic shutdown of the reactor and flush it with nitrogen if preset parameter limits were exceeded.

Pretest and post-test characterizations of the catalyst were performed by the analytical services group of the Power Systems Division.

The experimental apparatus operated without serious difficulty. In experiments where the reactant mixture was being changed, care had to be exercised that the liquid feed lines were thoroughly degassed to keep vapor lock from stopping the pumps.

Catalyst. Chemical characterization of catalyst T2130, United Catalysts, Inc., is given in Table 4. Two catalyst particle sizes were used in the experimental program, 1/16-inch granules and 1/8-inch pellets. The granules, obtained from the manufacturer, were taken from the dried filter cake of catalyzer precipitate, before it had been pelletized in the manufacturing process. This material was pelletized by the manufacturer to produce the 1/8-inch pellets.

Before each experiment, the catalyst was reduced in flowing hydrogen by following a schedule in which hydrogen was gradually increased in concentration from 1% in helium to 100% over a 4-hour period, at 400°F.

TABLE 4. T2130 CATALYST SPECIFICATION

| Chemical Composition | Percent by Weight |
|---|---|
| CuO | 33 (±3) |
| ZnO | 65 (±3) |
| $Al_2O_3$ | 0 to 2 |
| Na | Approximately 0.1 |
| Chloride | Less than 100 ppm |
| **Physical Characteristics** | |
| Bulk Density | 80 (±5) $lb/ft^3$ |
| Crush Strength (Side) | 15 lb |
| Surface Area | 30 (±5) $m^2/g$ |

Methanol. Fisher reagent-grade methanol was used in all but one experiment. Manufacturer's purity specificatons are shown with additional analyses for ethanol, sulfur, and chlorine in Table 5. Chlorine consistently appeared in

TABLE 5. METHANOL ANALYSIS

(Fisher Certified ACS)

| MANUFACTURER'S SPECIFICATION | |
|---|---|
| *Residue After* Evaporation | (5 ppm) |
| Acetone, Aldehydes | About 0.001% Acetone |
| Acidity (as *HCOOH*) | 0.002% |
| Alkalinity (as $NH_3$) | *3 ppm* |
| ANALYSIS FOR THIS STUDY | |
| Sulfur | Less than 0.05 ppm |
| Chloride | 0.5 ppm |
| Ethanol | 20 ppm |

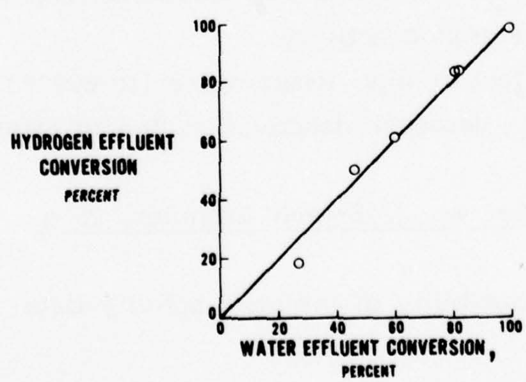


Figure 7. Methanol Conversion Calculated from Water and from Hydrogen Reactor Effluent

this and analyses of other reagent grade methanols, in the 0.5 to 1.0 ppmw range. Manufacturers cleaimed that methanol left their production process with chlorine content at less than the detection limit and hence that the chlorine observed in our samples must have entered during subsequent handling.

In one experiment, a less pure grade of methanol, Fisher "Purified," was used. It was described as 99%, and was shown by gas chromatography to contain about 100 ppmw ethanol, along with other unidentified impurities.

Experimental Procedure. The testing sequence is defined, below, with a list of the objectives of each test. Unless otherwise stated, the standard reactant feed was a mixture of water and methanol in the ratio of 1.5 to 1.

Catalyst Charge No. 1: 1/16-Inch Granules, 99 g.

Determine intrinsic activity of catalyst as a function of time at 400°F. Monitor conversion at setpoint for 500 hours.

Determine effect of total pressure on catalyst activity.

Determine effect of variation in steam/methanol ratio on catalyst activity.

Catalyst Charge No. 2: 1/8-Inch Pellets, 99 g

Determine effect of particle size on catalyst activity

Catalyst Charge No. 3: 1/8-Inch Granules, 99 g.

Determine effect of ethanol and isobutanol impurity on methanol steam reforming activity.

Determine effect of high temperature (to 600°F) on catalyst activity. Measure deactivation due to catalyst sintering.

Catalyst Charge No. 4: 1/16-Inch Granules, 25 g.

Check reproducibility of intrinsic activity data.

Catalyst Charge No. 5: 1/8-Inch Pellets, 25 g.

Check reproducibility of pellet activity data.

EXPERIMENTAL RESULTS. The experimental results of the program are reported in the following paragaphs on catalyst activity and stability, reactor operating parameters, and variations in catalyst and product properties.

Intrinsic Activity of T2130 Catalyst. For each experiment, the conversion of *methanol was* plotted as a function of the theoretical hydrogen space velocity, THSV. The THSV was calculated assuming reaction to occur as in Equation (1) above. A typical plot is illustrated in Figure 8. The data was analyzed assuming a pseudo-first-order dependence of rate on methanol pressure. Since the data was taken at appreciable conversions, an integrated form of the rate law, including volume expansion due to conversion, was employed, based on the stoichiometric conversion to carbon dioxide as in Equation (1).

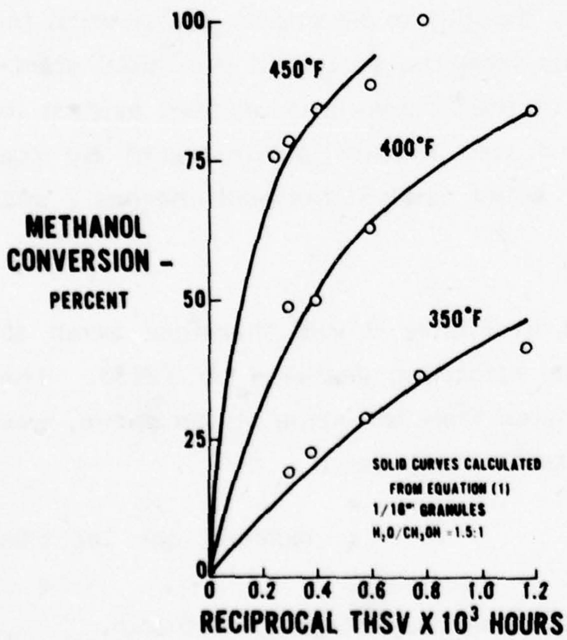


Figure 8. Steam Reforming Methanol: Conversion versus Space Velocity for T2130 Charge No. 1

A value for k, the pseudo-first-order rate constant, was obtained by a visual best fit to the data points using the expression:

$$\frac{W}{F_o} = \frac{1}{kp_o}\left[(1+\varepsilon)\ln\frac{1}{1-\alpha} + \varepsilon\,\alpha\right]$$

where: $W$ = catalyst weight, grams

$F_o$ = initial methanol flow rate, moles/sec

$p_o$ = initial methanol pressure, atmospheres

$\alpha$ = fractional conversion of methanol

$\varepsilon$ = expansion factor (0.8 for $H_2O/CH_3OH$ = 1.5)

The rate constants so obtained were plotted in an Arrhenius plot, as a function of reciprocal temperature, in Figure 9. Data from three separate charges of catalyst are shown. Values for k from charges 3 and 4 are in good agreement, but the rate constants from charge 1 are significantly less. This difference in activity is demonstrated for the conversion data in Figure 10.

The lower activity of the first charge was thought to be due to deactivation by residual poisons, probably sulfur, flushed from the system in the initial start-up of the reactor. The reproducibility in the activity measurement evident in the agreement between charges 3 and 4 was further demonstrated by the agreement in activity values for 1/8-inch pellet catalyst between charges 2 and 5, discussed later.

The curve defined by charges 3 and 4 in Figure 9 was therefore taken to represent the intrinsic activity for steam reforming methanol on T2130. The activation energy for the reaction, calculated from the slope of the curve, was 27.03 kcal/g mole, and the first-order rate constant was:

$$k = 7.2 \times 10^7 \exp\left(\frac{-27{,}030}{RT\ {}^{\circ}K}\right) \quad \text{g moles/g cat sec atm}$$

This was the baseline activity of the catalyst on reagent-grade methanol.

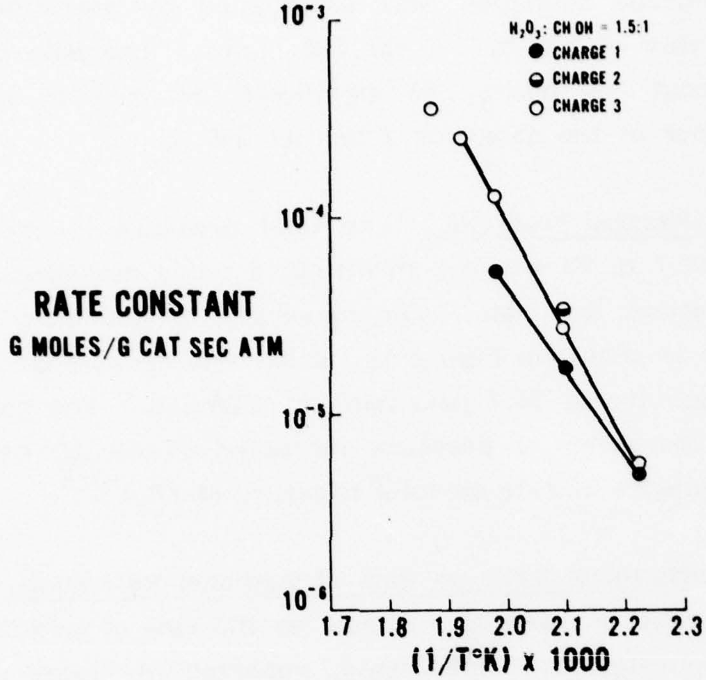


Figure 9. Arrhenius Plot for Steam Reforming Methanol

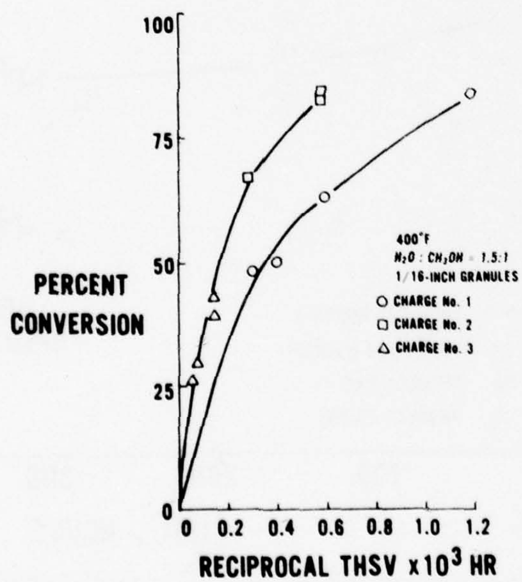


Figure 10. Activity of T2130 for Methanol Reforming

Stability of Catalyst Activity. The long-term endurance of catalyst activity, using reagent-grade methanol, was established by operating the catalyst at 400°F and a THSV of 852 $hr^{-1}$, for 500 hours. The data of Figure 11 show that, after about 100 hours, no significant decrease in activity occurred, within the scatter of the data, for a further 400 hours.

Effect of Total Reactor Pressure. The total pressure in the reactor was increased from 14.7 to 50 psia by throttling a valve downstream of the reactor, at constant reactant flow rate. The conversion of methanol, determined at the two pressures, is shown in Figure 12, which also shows that after operation at 50 psia, the activity at 14.7 psia had not changed. The conversion and the rate constant decreased as pressure increased (Table 6) by an amount that yielded a dependence of rate on total pressure of $(P_t)^{-0.3}$.

Effect of Steam/Methanol Ratio on Rate of Methanol Reforming. The effect of a change in the ratio of water to methanol on the rate of methanol steam reforming was demonstrated by experiments, reported in Figure 13. At constant

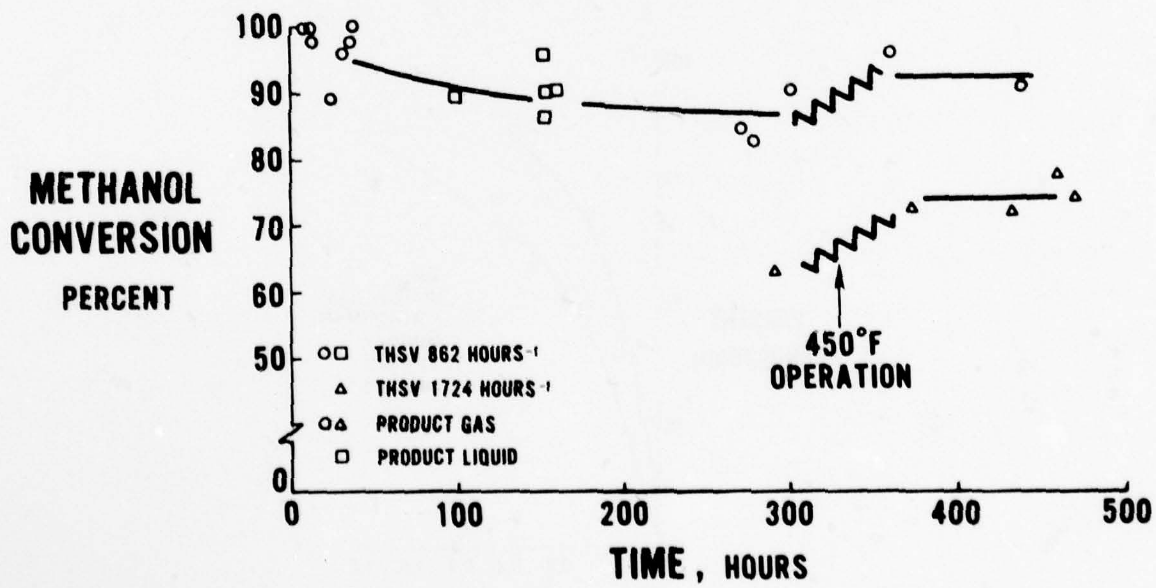


Figure 11. Methanol Steam Reforming on T2130, 500-Hour Endurance

TABLE 6. EFFECT OF TOTAL REACTOR PRESSURE ON REACTION RATE

(Conditions: 400°F, $H_2O:CH_3OH$ = 1.5:1)

| Reactor Pressure, psia | Rate Constant, moles/g cat sec atm | Initial Rate, moles/g cat hr |
|---|---|---|
| 14.7 | $1.65 \times 10^{-5}$ | $2.38 \times 10^{-2}$ |
| 50 | $3.48 \times 10^{-6}$ | $1.7 \times 10^{-2}$ |

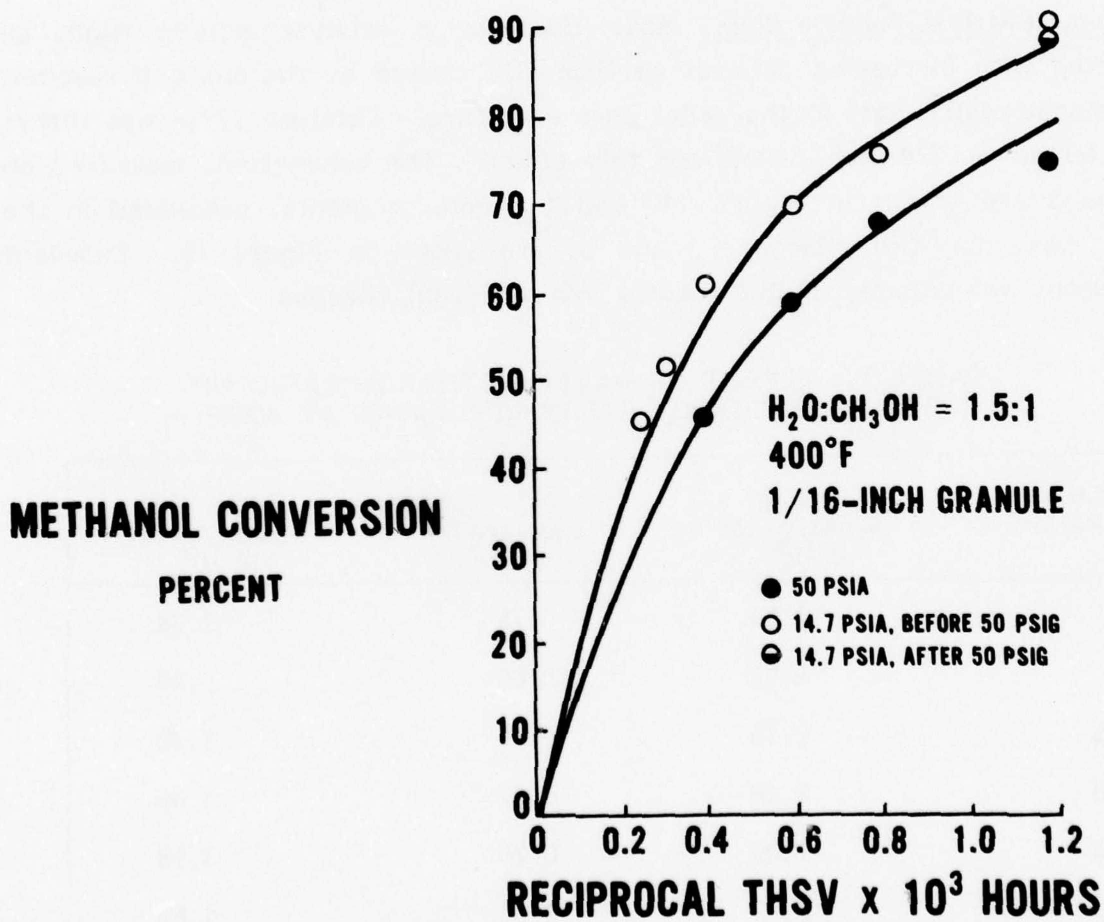


Figure 12. Steam Reforming Methanol: Effect of Total Pressure

temperature, 400°F, and constant liquid feed rate, the $H_2O/CH_3OH$ mole ratio was varied from 1.5 to 0.7. The conversions measured for the lower ratios of feed composition were less, but the rates of methanol conversion increased slightly as the ratio decreased (Table 7). The time at a given fuel ratio was not always sufficient for the conversion to reach a steady value, but the experimental observations were thought to be sufficient to define behavior expected from brief excursions of feed composition. No increase in the pressure drop, $\Delta P$, across the catalyst bed was observed in up to 25 hours of operation at low fuel $H_2O/CH_3OH$ mole ratios. Also, no change in the benchmark activity (400°F, 1724 $hr^{-1}$ THSV, $H_2O/CH_3OH$ = 1.5) was measured after 200 hours of operation with feeds at lower $H_2O/CH_3OH$ ratios.

Effect of Catalyst Particle Size. Some decrease in catalyst activity might be expected with increasing catalyst particle size caused by the onset of reactant diffusional restrictions in the pellet pore structure. Catalyst T2130 was therefore tested as 1/8-inch pellets for this effect. The conversions measured on charge 3 are shown in Figure 14, and the rate constants, calculated in the usual way, for two charges, 3 and 5, are shown in Figure 15. Excellent agreement was obtained in the results from different charges.

TABLE 7. EFFECT OF WATER-METHANOL RATIO ON RATE OF METHANOL STEAM REFORMING AT 400°F

| $H_2O:CH_3OH$ Mole Ratio | F/W moles/g cat hr X $10^2$ | Conversion | Initial Rate, moles/g cat hr X $10^2$ |
|---|---|---|---|
| 1.5 | 1.84 | 0.75 | 1.38 |
| 1.0 | 2.12 | 0.66 | 1.40 |
| 0.95 | 2.15 | 0.65 | 1.40 |
| 0.90 | 2.18 | 0.67 | 1.46 |
| 0.80 | 2.26 | 0.70 | 1.58 |
| 0.70 | 2.33 | 0.67 | 1.56 |

Rate = $\alpha$ F/W, 2 ml/min liquid feed, 16.4 g catalyst

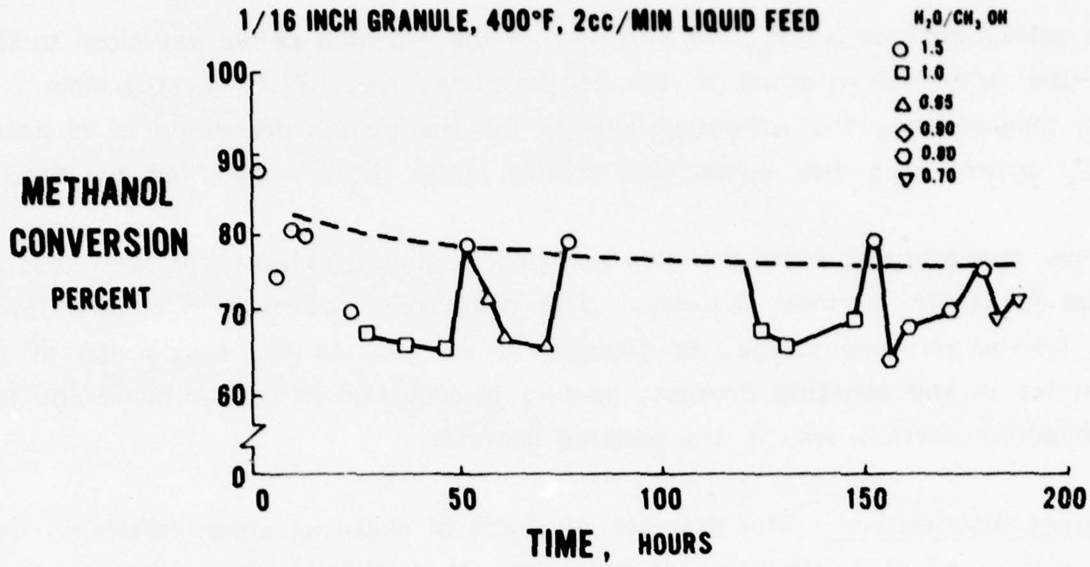


Figure 13. Steam Reforming Methanol: Effect of $H_2O/CH_3OH$ Ratio

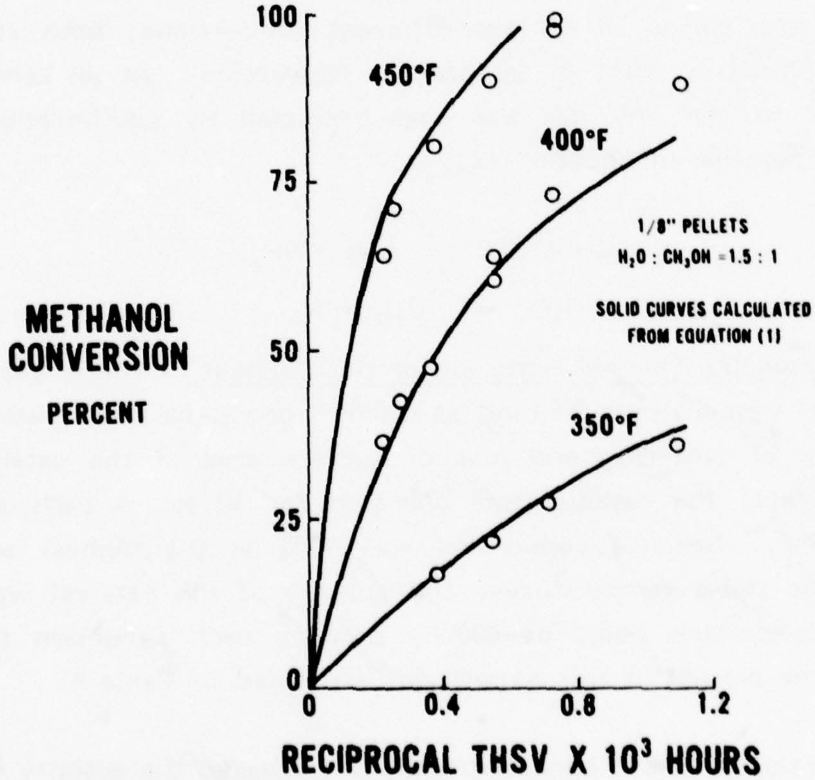


Figure 14. Steam Reforming Methanol: Conversion versus Space Velocity

The activation energy, $E_a$, for reaction on the 1/8-inch pellet was close to that for the 1/16-inch granule at low temperature, i.e., 27.03 kcal/g mole. At high temperature, the activation energy for the pellets decreased to 19 kcal/g mole, approaching the value 13.5 kcal/g mole, $E_a/2$, predicted by theory.

At low temperature, both granules and pellets should exhibit the same absolute value for their intrinsic activity. The difference observed in Figure 15, in the low-temperature range, is thought to be due to the compaction of the granules in the pelleting process, leading to occlusion of copper metal and loss of effective surface area in the pelleted material.

Product Distribution. The dry gas products of methanol steam reforming were CO, $CO_2$, and $H_2$. No $CH_4$ was detected. In each experiment these products appeared to be in shift equilibrium with $H_2O$. This is demonstrated in Figure 16 for an experiment in which the ratio $H_2O/CH_3OH$ was 0.2. The reactant space velocity was varied to achieve different conversions, both above and below the stoichiometric point of 20 percent conversion. At all conversions, the CO content in the dry gas was that predicted by equilibration of the products in the reaction of equation (3):

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2 \qquad (2)$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \qquad (3)$$

Deactivation Caused by Thermal Sintering of the Catalyst. There was concern that operation at temperatures as high as 600°F might cause deactivation of the catalyst because of sintering and loss of surface area of the catalyst. To evaluate this effect, the catalyst was operated for 50 hours each at 450°F, 550°F, and 600°F. Because conversion was 100% at the highest achievable space velocity at these temperatures, the activity of the catalyst was determined at the benchmark point of 400°F, between each excursion to higher temperature. The results of this experiment are listed in Table 8.

The initial excursion of 450°F appeared to have increased the activity of the catalyst. It was possible that the catalyst may have been incompletely regenerated

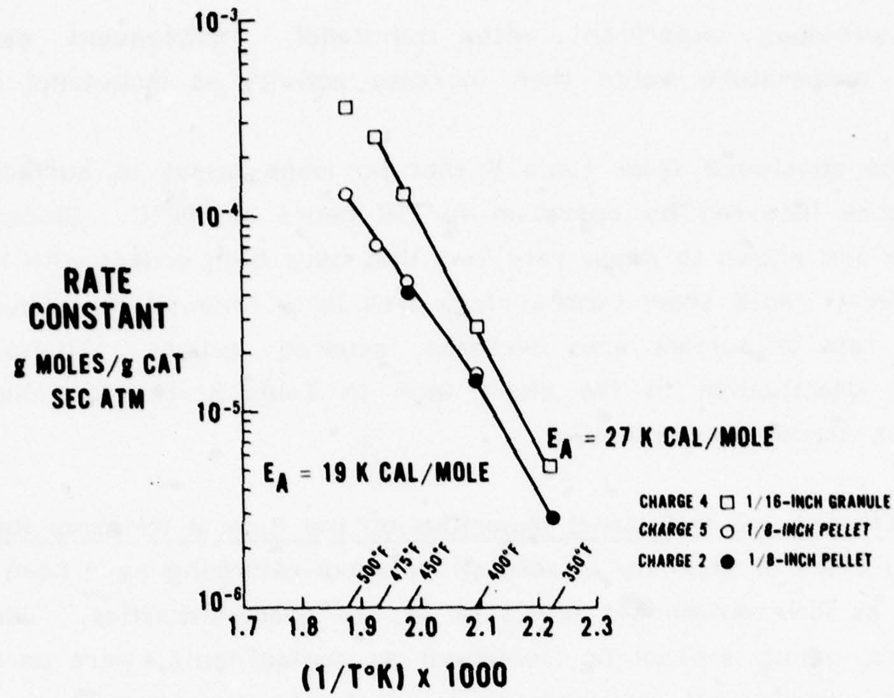


Figure 15. Arrhenius Plot for Steam Reforming Methanol

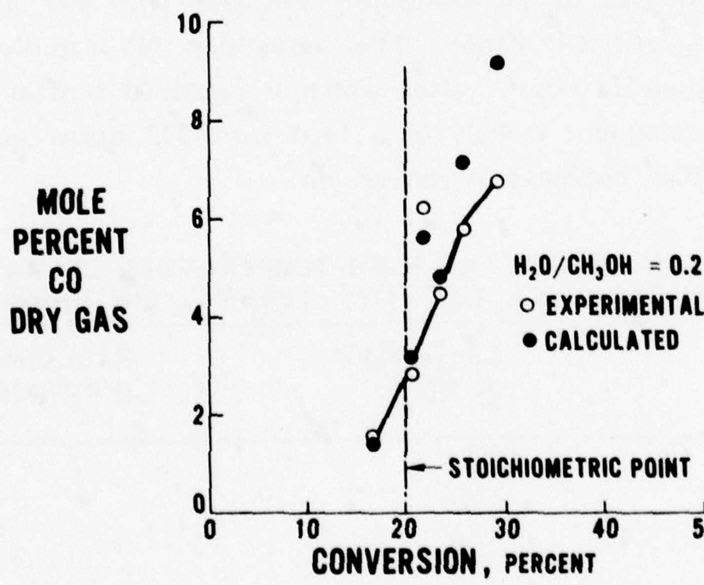


Figure 16. Equilibration of Products of Methanol Steam Reforming at 400°F

after a previous experiment with isobutanol. Subsequent experiments at higher temperature would then increase activity as *isobutanol desorbed*.

It could be concluded from Table 8 that no large losses in surface area of catalyst were incurred by operation for 50 hours at 600°C. Since sintering phenomena are known to follow rate laws that have high orders with respect to time,[5] a very rapid short-term surface area loss, followed by a much slower long-term rate of surface area decrease, generally occurs. The absence of significant deactivation in the short term in Table 8 therefore implies that longer-term deactivation was slow.

Effect of Ethanol and Isobutanol Impurities on the Rate of Methanol Reforming. Previous studies of impurity effects on methanol reforming have been performed either at low contaminant levels or at low space velocities. The present experiments, using ethanol or isobutanol as contaminants, were performed at high space velocity and concentration to accelerate the resulting deactivation. A catalyst charge of 1/16-inch granules of T2130 was "lined out" on reagent-grade methanol for 90 hours at 400°F and 1724 $hr^{-1}$ THSV (Figure 17). The feed was then switched to one containing methanol with 400 ppmw ethanol but with the same $H_2O/CH_3OH$ ratio. The conversion fell rapidly from 85 to 46 percent in less than 20 hours, after which it remained constant for more than 80 hours. A subsequent switch to a feed with 800 ppmw ethanol produced only a slight further decrease in conversion.

TABLE 8. EFFECT OF HIGH-TEMPERATURE OPERATION ON CATALYST ACTIVITY (THERMAL SINTERING)

| Treatment | Conversion* at 400°F | Rate Constant at 400°F g moles/g cat sec atm X $10^5$ |
|---|---|---|
| 400°F, initial | 0.70 | 2.02 |
| 450°F, 60 Hours | 0.78 | 2.6 |
| 550°F, 50 Hours | 0.85 | 3.5 |
| 600°F, 60 Hours | 0.78 | 2.6 |

*Conversion and rate constant determined at 400°F, 724 $hr^{-1}$ THSV, following operation at temperature in first column.

5. J.A.S. Bett, K. Kinoshita, and P. Stonehart, J. Catal., 35, 307 (1974).

Upon reversion to reagent-grade methanol, the conversion rapidly recovered its initial value. A feed containing 100 ppmw ethanol gave similar deactivation behavior, but achieved a steady-state activity intermediate between methanol containing 400 ppm ethanol and reagent-grade methanol.

In Figure 18, a similar response of the catalyst to isobutanol impurity is shown. The catalyst rapidly approaches a reduced steady-state value for activity that is close to the minimum value observed for poisoning with ethanol, but for isobutanol the minimum value is achieved at lower impurity concentration. From this data, relative rates, normalized to the catalyst activity with reagent-grade methanol, were calculated using the pseudo-first-order procedure. These were plotted versus impurity level in Figure 19.

Increasing temperature increased the rate of steam reforming for methanol contaminated with 200 ppm ethanol, as shown in Figure 20. The apparent activation energy was close to that measured for reagent-grade methanol.

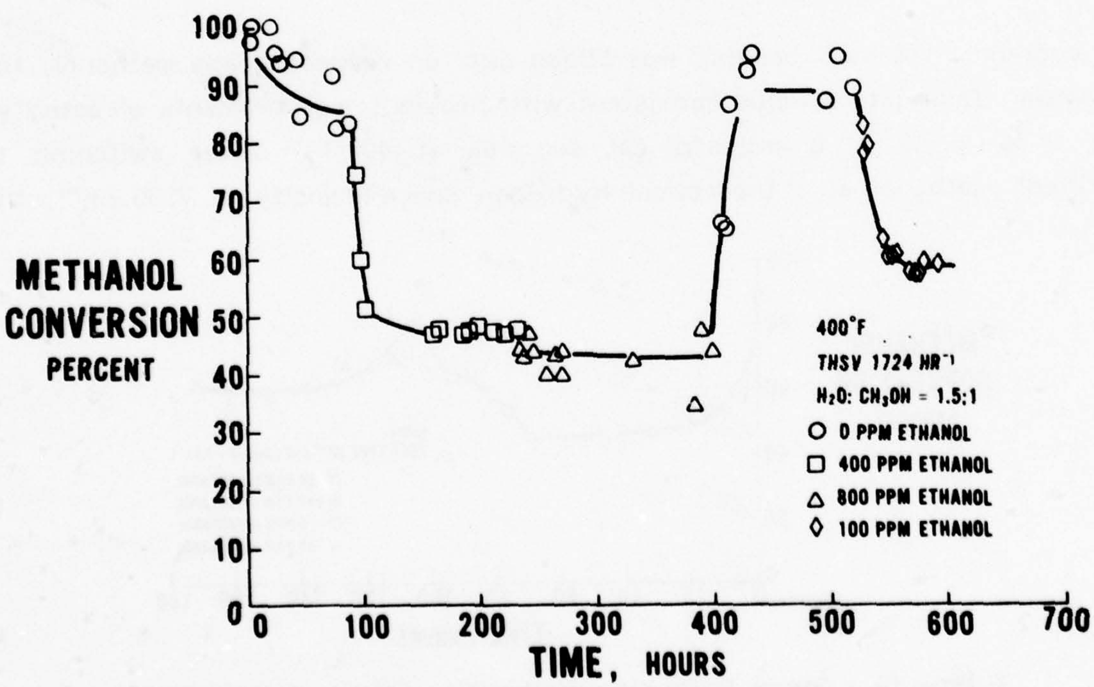


Figure 17. Steam Reforming Methanol: Effect of Ethanol

The trapping efficiency of the downstream condensers was not sufficient to determine the conversion of ethanol or isobutanol in these experiments. Chromatographic analysis of the effluent liquid confirmed that unreacted ethanol and isobutanol were present, but the conversion could not be estimated.

Steam Reforming "Technical" Grade Methanol. All the preceding experiments used reagent-grade methanol as reactant. Most previous studies in the literature, particularly those using a less pure, technical-grade methanol, have reported slow deactivation of copper zinc-oxide catalysts, continuing over hundreds of hours. In contrast, our experiments with ethanol and isobutanol impurity suggested that, at very high space velocity or impurity concentration, the copper catalyst deactivated rapidly to a steady-state value associated with equilibrium coverage of impurity. To confirm this observation, and to determine the effect of other impurities present in less pure methanol, a catalyst charge was run at very high space velocity, on "purified," technical-grade methanol. This fuel was analyzed and found to contain about 100 ppmw ethanol, among the other unidentified impurities.

The catalyst, 1/8-inch pellets, was "lined out" on reagent-grade methanol, the conversion falling to a value consistent with previous measurements of activity, i.e., $1.56 \times 10^{-5}$ g moles/g cat sec atm at 400°F. After switching to "purified" methanol at a theoretical hydrogen space velocity of 7500 $hr^{-1}$, the

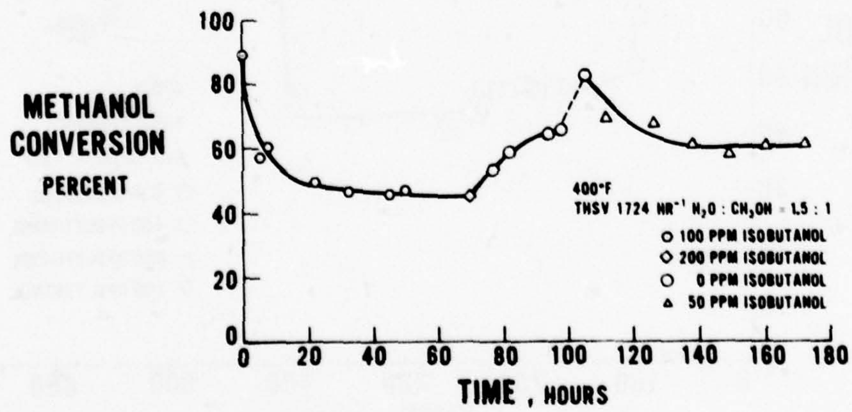


Figure 18. Steam Reforming Methanol: Effect of Isobutanol

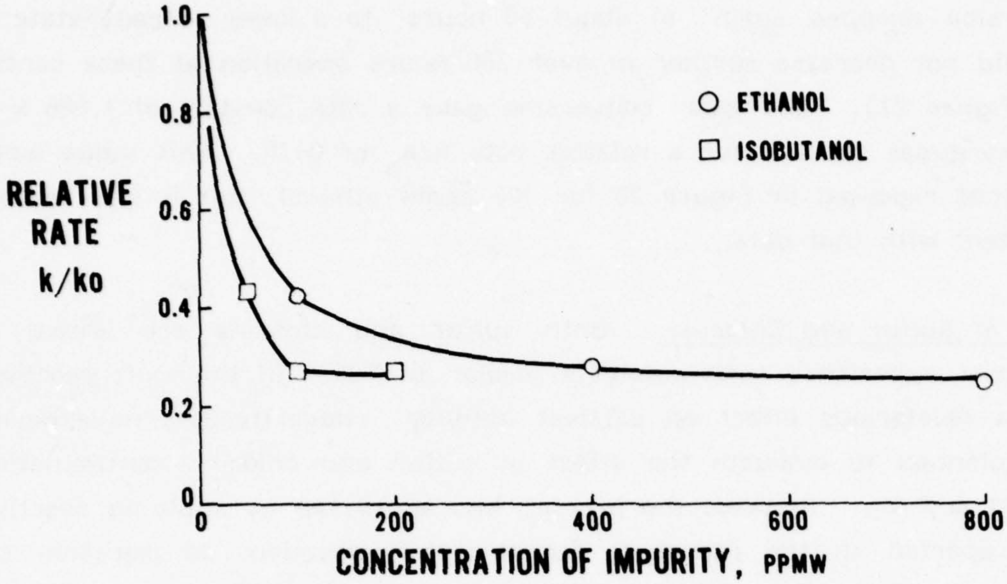


Figure 19. Effect of Higher Alcohols on Rate for Methanol Reforming at 400°F

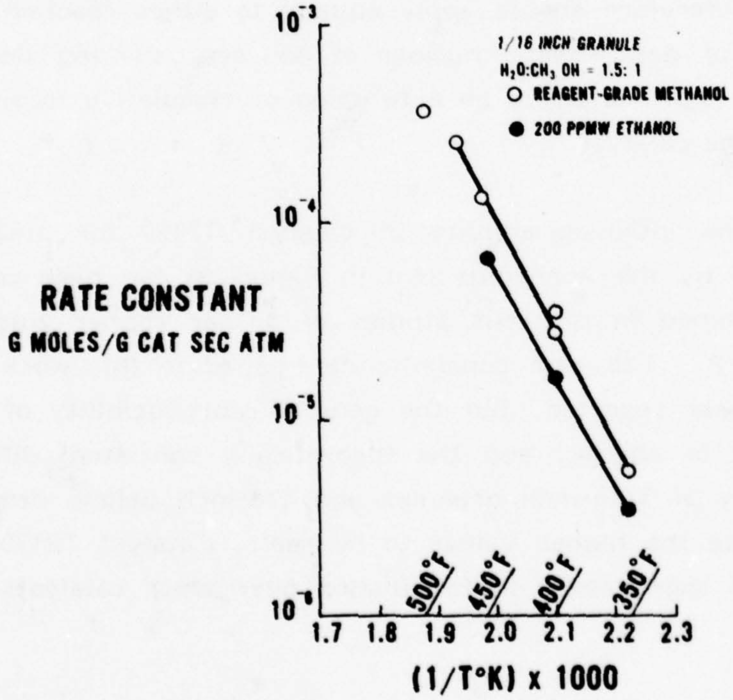


Figure 20. Effect of Ethanol on Rate for Steam Reforming Methanol

conversion dropped again, in about 50 hours, to a lower, steady-state value that did not decrease further in over 200 hours operation at these conditions (see Figure 21). The lower conversion gave a rate constant of $1.086 \times 10^{-5}$ g moles/g cat sec atm for a relative rate $k/k_o$ of 0.70. This value was less than that reported in Figure 20 for 100 ppmw ethanol, but it was reasonably consistent with that data.

Effect of Sulfur and Chlorine. Both sulfur and chlorine are known, from industrial experience with catalysts similar to T2130 in the shift reaction, to have a deleterious effect on catalyst activity. Nevertheless, no experiments were planned to evaluate the effect of sulfur and chlorine contamination on catalyst activity. Instead, the problem was addressed by applying deactivation data reported in the literature for the shift reaction, to methanol steam-reforming. This was judged to be a reasonable procedure for estimation of these effects, since sulfur acts to obscure active copper surface adsorption, and chlorine acts to accelerate catalyst sintering and loss of surface area. Both phenomena therefore should apply equally to either reaction. Figure 22 is a compilation of data from a number of sources, showing deactivation of copper-containing shift catalysts as a function of cumulative loading of sulfur and chlorine on the catalyst.

DISCUSSION. The intrinsic activity of catalyst T2130 for steam reforming methanol, defined by the Arrhenius plot in Figure 9, has been compared with the values determined in previous studies of similar copper zinc-oxide catalysts, in Figure 2. The rate constants determined in this work are greater than any previously reported, but the general reproducibility of the present data from charge to charge, and the theoretically consistent differences between the activity of 1/16-inch granules and 1/8-inch pellets demonstrated in Figure 15, indicate the higher values to be real. Catalyst T2130 must therefore represent an improvement in formulation over other catalysts represented in Figure 2.

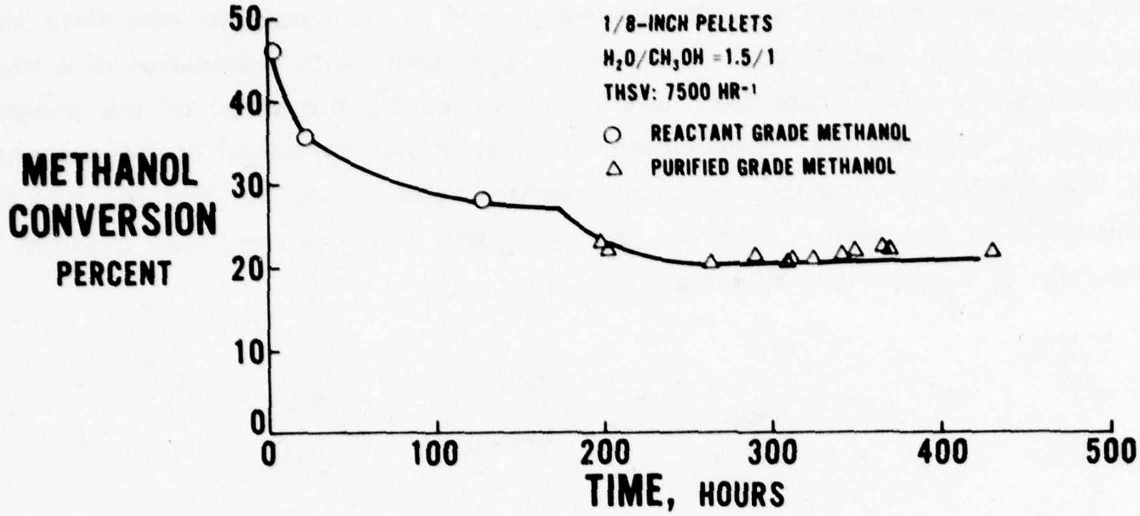


Figure 21. Steam Reforming "Purified-Grade" Methanol

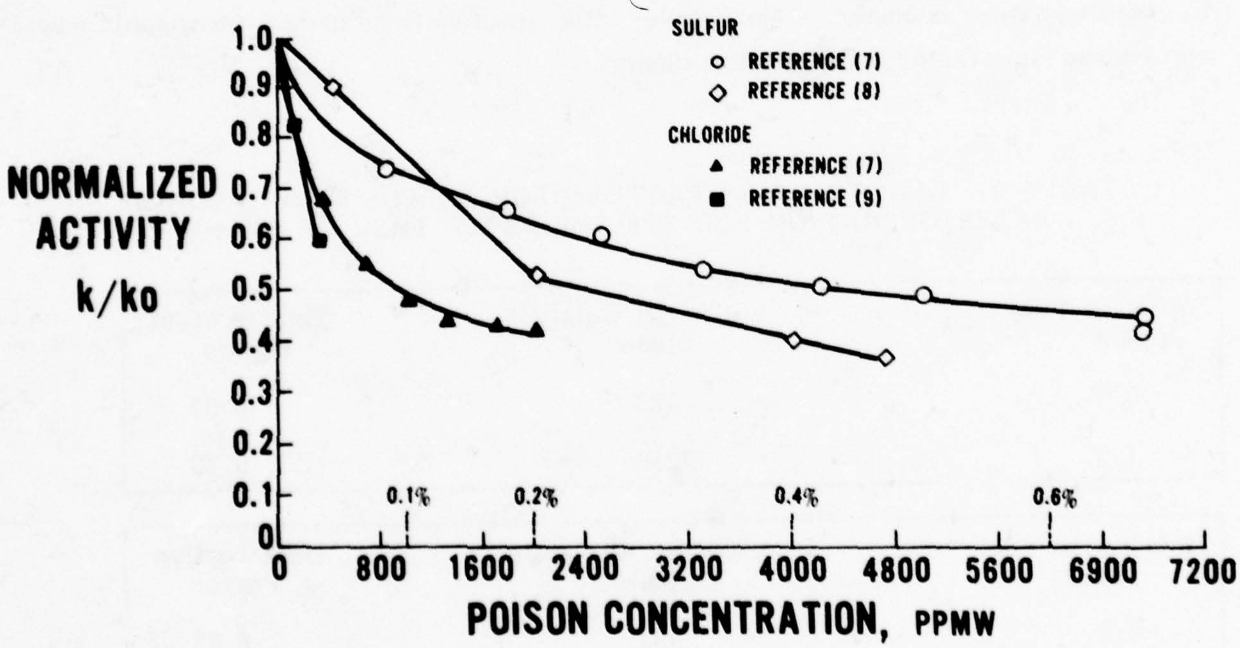


Figure 22. Effect of Sulfur and Chlorine Poisoning on Activity of Low-Temperature Shift Catalysts

The pseudo-first-order kinetic treatment used to analyze the rate data was recognized as a simplification. A complex treatment, with elucidation of a more fundamentally sound rate law, was not justified by the scope of the present program. Nevertheless, some kinetic information was contained in the response of the system to variations in total pressure, space velocity, and $H_2O/CH_3OH$ mole ratio of the feed. However, no consistent interpretation was possible in the form of a power law rate equation, i.e.,

$$\text{rate} = k \quad P^{m}_{\text{methanol}} \quad P^{n}_{H_2O}$$

Using computation techniques, a best fit to the conversion versus space velocity curves and the $(P_t)^{-0.3}$ dependence of pressure was obtained with values for m = 1.5 and n = -1.8. But the dependence of rate on $H_2O/CH_3OH$ mole ratio, given in Table 7, would only permit a fit to m = 0, n = -0.3. Experiments designed specifically to elicit kinetic information would be required to resolve this anomaly. Meanwhile, the pseudo-first-order treatment was considered satisfactory for reactor design.

TABLE 9. DEACTIVATION FACTORS FOR SULFUR AND CHLORINE AFTER OPERATION FOR 8000 HOURS AT THSV OF 580 HR

| Sulfur in Fuel ppmw | Sulfur in Catalyst ppmw | Deactivation Factor |
|---|---|---|
| 0.1 | 123 | 0.93 |
| 1.0 | 1230 | 0.70 |

| Chlorine In Fuel ppmw | Chlorine in Catalyst ppmw | Deactivation Factor |
|---|---|---|
| 0.1 | 123 | 0.83 |
| 1.0 | 1230 | 0.45 |

Similarly, the cursory investigation of sintering at high temperature, of effects of $H_2O/CH_3OH$ mole ratio, and of total pressure were intended only to determine the short-term effects of excursions of the power plant reformer from rated conditions. Longer-term endurance testing would be required to ensure the absence of deactivation at low $H_2O/CH_3OH$ ratio or high temperature. In particular, the steady-state values for activity reported for ethanol and isobutanol-contaminated methanol in Figures 17 and 18 should be measured for longer times to detect possible deactivation by reaction of surface-adsorbed species.

A unique feature of the present study was the response of the rate of steam reforming methanol to contamination by higher alcohols. The rapid decrease in activity upon exposure to low levels of higher alcohol concentration, and its rapid reversal upon removing the contaminant, indicated that the decrease was caused by preferential coverage, at steady state, of the active copper surface by the higher molecular weight species. That isobutanol produced a "saturation" deactivation to the same value as ethanol, but at lower partial pressures, is consistent with a higher heat of adsorption of isobutanol. The rate of desorption of isobutanol also appeared slightly slower than ethanol (Figures 17 and 18), again consistent with this interpretation.

Previous workers, in demonstrating effects of contaminants, have used lower levels of contaminant, or lower space velocities, and consequently the effects reported have been gradual reductions in activity, not recognized as reversible adsorption. Only Leesona Moos Laboratory, using 500 ppmw concentrations of a variety of organic contaminants, reported deactivation comparable to Figure 17. They did not report, however, that this effect was reversible.

The experiment with "purified" grade methanol reported in Figure 21 confirmed that other impurities likely to be found in less pure methanols behaved in a manner similar to ethanol and isobutanol. A steady-state, deactivated activity could therefore be predicted for technical-grade methanols.

The stated goal of this study was to define a baseline activity for steam reforming methanol on T2130 catalyst. In addition, correction factors were to be defined for various deactivation mechanisms that would permit adjustment of the baseline activity to the lower value expected at the end-of-life for the power plant, i.e., 8000 hours at rated power, 580 hr THSV. Thus, this study has quantified deactivation due to thermal sintering and to contamination by sulfur, chlorine, ethanol, and isobutanol. The end-of-life activity may then be estimated by application to the baseline activity of any combination of deactivation factors representing the conditions at which the power plant is expected to operate, e.g.,

$$k_{End\text{-}of\text{-}life} = k_{Baseline} \; \eta_{EtOH} \; \eta_{Isob} \; \eta_S \; \eta_{Cl} \; \eta_{Sinter}$$

An advantage of this approach is flexibility in permitting the tradeoffs between fuel purity, fuel availability, and power plant efficiency and lifetime to be readily evaluated by insertion of the appropriate rate constant in the design model.

A more detailed discussion of each deactivation factor follows.

DATA INPUT TO REACTOR DESIGN. The data input to the reactor design is described in the following paragraphs on baseline activity; deactivation factors for sintering, suflur, chlorine, higher alcohols; and rate constant for methanol steam reforming.

Baseline Activity. The baseline activity of catalyst T2130 was the intrinsic activity defined by the Arrhenius plot of Figure 9 and by the rate constant

$$k = 7.2 \times 10^7 \exp\left(\frac{-27{,}030}{RT^\circ K}\right) \frac{\text{g moles}}{\text{g cat sec atm}}$$

This value was fixed for operation at a mean reactor temperature of 400°F, on reagent-grade methanol with a $H_2O/CH_3OH$ ratio of 1.5. It is possible, however, that operating transients in the boiler might result in delivery of feed

with lower values for this ratio for short times. The experiments of Figure 13 show no detrimental effect on activity at baseline conditions after brief times with feed ratios as low as 0.7. Furthermore, the rates for methanol conversion at the lower value for feed ratio increased; hence, no deactivation factor was included for variation in $H_2O/CH_3OH$ feed ratio.

Likewise, although increase in pressure lowered catalyst activity, no change was observed on return to baseline conditions; therefore, no deactivation factor was included for pressure variation.

The baseline activity is the intrinsic activity of the catalyst exhibited by small particles at lower temperature. Adjustment of this value for the effect of diffusion of reactants in the pores of pelleted catalyst, i.e., the effectiveness factor, was included in the reactor design model.

Sintering Deactivation Factor, $\eta_{Sinter}$. No deactivation of the catalyst was indicated in Table 8 by 50 hours operation at up to 600°F. Young and Clarke,[6] however, claim a 1.4 percent loss in activity per 1000 hours of operation at 500°F because of thermal sintering. An effect of this magnitude would have escaped our detection. We therefore apply a correction factor of 0.89 for 8000 hours of operation at a mean temperature of 500°F.

Sulfur Deactivation Factor, $\eta_S$. The curves for sulfur deactivation in Figure 22 were used to estimate deactivation factors for the methanol steam-reforming reaction, after 8000 hours of operation at the space velocity required for rated power, 580 $hr^{-1}$, and at two contaminant levels, in Table 9. Since the source of sulfur is immaterial to the ultimate response of the catalyst, the figure for sulfur concentration in methanol must be regarded as a value for fuel-equivalent concentration. Thus, for example, the 0.1 ppm value assumes zero sulfur concentration in water. Any sulfur appearing in the water portion of the feed requires an equivalent subtraction from the designated level in methanol.

6. P. W. Young and C. B. Clarke, Chem. Eng. Prog. 69, 69, (1975)

<u>Chlorine Deactivation Factor,</u> $\eta_{Cl}$. A treatment of chlorine contamination, analogous to that for sulfur, has been given in Table 9. The deactivation factors for chlorine are greater than for sulfur, in keeping with industrial experience. The combined chlorine content of both methanol and water would have to meet the designated methanol fuel equivalent concentration. However, since relatively impure water supplies can be readily purified to less than 0.1 ppm levels of both chlorine and sulfur by passage through standard ion-exchange beds, it is probable that the entire contaminant concentration could be assigned to the methanol specification.

<u>Deactivation by Higher Alcohols,</u> $\eta_{EtOH}$, $\eta_{Isob}$. Figures 17 and 18 imply that higher alcohols are reversibly adsorbed on the catalyst to give, at saturation coverage of either ethanol or isobutanol, a constant activity that would be accounted for by a deactivation factor of 0.25.

Projections[2] for methanol produced from coal gasification processes (methyl fuel) predict ethanol and isobutanol concentrations of about 500 and 2500 ppm, respectively, for this fuel. Therefore, saturation coverage would be reached and the deactivation factor would be 0.25.

The ethanol specification for methanol used in the power plant may be dictated by consideration of the availability of supplies of commercial methanol at a given ethanol level. Baseline activity was defined for reagent-grade methanol with less than 20 ppm ethanol, for which the deactiviation factor would be unity. Figure 23 shows the cumulative commercial production of methanol, from U.S. manufacturers in 1973, versus the respective ethanol content as the only major contaminant. From this figure the ability of the power plant to handle 100 ppmw ethanol would render available 40 percent of the commercially produced methanol. For this result, a deactivation factor of 0.42 would have to be applied to the baseline catalyst activity value.

<u>Methanol Steam Reforming Rate Constant for the 1.5-kW Fuel Cell Design Model.</u> The final end-of-life value for the rate constant used in the design model was obtained by applying the various deactivation factors described above. The particular values used depend on the conditions of operation and on the purity of the methanol selected as feedstock. An example of the application of these factors is given in Table 10.

The values for rate constants used in the design model calculations in this study were based on a baseline activity of

$$k = 5.28 \times 10^3 \quad \exp\left(\frac{-18,513}{RT}\right) \quad \frac{\text{g moles}}{\text{g cat sec atm}}$$

This value is lower than that in Table 9 and was obtained from charge 1, in Figure 9, i.e., at the start of the experimental program. When the true value for the intrinsic activity was found to be higher, the lower value in the model was not changed since it was considered conservative.

A more extended development program would employ the higher value.

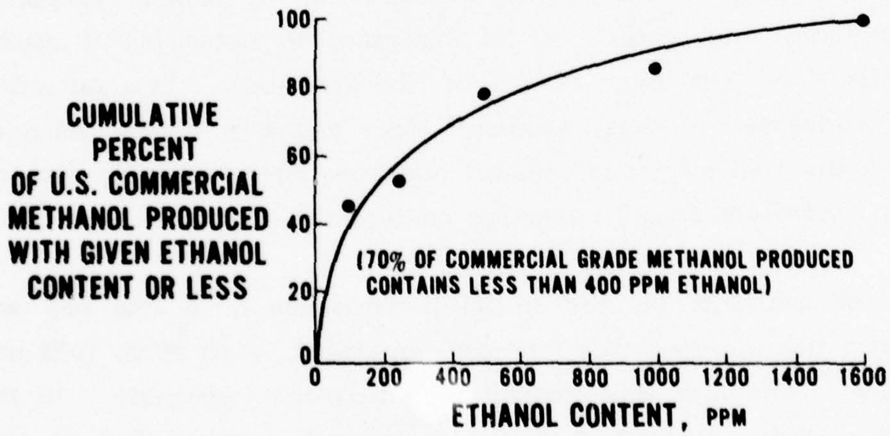


Figure 23. Ethanol Content of Commercial-Grade Methanol As of 1973

TABLE 10. RATE CONSTANT FOR STEAM REFORMING METHANOL ON T2130

$$k_{BASELINE} = 7.2 \times 10^7 \exp \frac{-27,030}{RT\ ^\circ K} \quad \frac{\text{g moles}}{\text{g cat sec atm}}$$

| DEACTIVATION FACTORS FOR 8000-HOUR OPERATION, THSV 580 $HR^{-1}$ | |
|---|---|
| At 500°F mean temperature | 0.89 |
| S at 0.1 ppmw fuel effective | 0.93 |
| Cl at 0.1 ppmw fuel effective | 0.83 |
| Ethanol 100 ppmw | 0.42 |
| Other Alcohols < 20 ppmw | 1.0 |
| $k_{END\text{-}OF\text{-}LIFE} = 2.1 \times 10^7 \exp \frac{-27,030}{RT\ ^\circ K} \quad \frac{\text{g moles}}{\text{g cat sec atm}}$ | |

B. Effect of Methanol in Fuel Going to Power Section

The lack of 100% conversion in the methanol reforming process will result in fuel gas being supplied to the fuel cell power section that contains some methanol in addition to the normal products of hydrogen, carbon dioxide, carbon monoxide, and water. It is important to determine if methanol has adverse effects on the performance of the fuel cell. Two general problem areas were addressed in these studies: does methanol poison the oxidation of hydrogen at the fuel electrode (anode) and does methanol react with the phosphoric acid electrolyte at cell operating conditions?

The effect of methanol on the initial performance of a fuel cell anode was measured in a floating-electrode half-cell apparatus using 99 to 100% phosphoric acid at 375°F. The acid was cleaned with hydrogen peroxide. In this apparatus,[1] the IR-free polarization of a test electrode supported at the electrolyte surface was measured relative to a hydrogen electrode in the same electrolyte. Anode performance was measured on fuel containing methanol. The methanol was introduced in the fuel gas by passing the fuel gas through a bubbler containing methanol at room temperature, resulting in a fuel containing about 20% methanol. Finally, performance was once again measured on methanol-free

fuel to make sure that the methanol had no permanent effect on electrode performance. The results of this test are shown in Figure 24; the performance of an anode operating on pure hydrogen is also shown for comparison. The effect of the methanol was very slight, causing only an additional 3-mV polarization at a current of 500 ma/cm$^2$. This effect was reversible; normal performance was restored when the methanol was removed from the fuel.

The fuel-processing program was also concerned with reforming methanol containing common commercial impurities such as ethanol. These tests showed that, for the most part, the ethanol would pass through the reformer. Estimates indicate concentrations of ethanol as high as 800 ppm could be present in the fuel gas being supplied to the fuel cell. Half-cell performance tests with about 6% ethanol in the fuel gas were done in a manner identical to those for methanol as discussed above. The effect on initial anode performance is shown in Figure 24. The effect was greater than that observed for methanol, but still only a small effect overall; only 5 mV additional polarization at 500 ma/cm$^2$. Removal of the ethanol restored initial anode performance, showing no permanent performance loss attributable to ethanol.

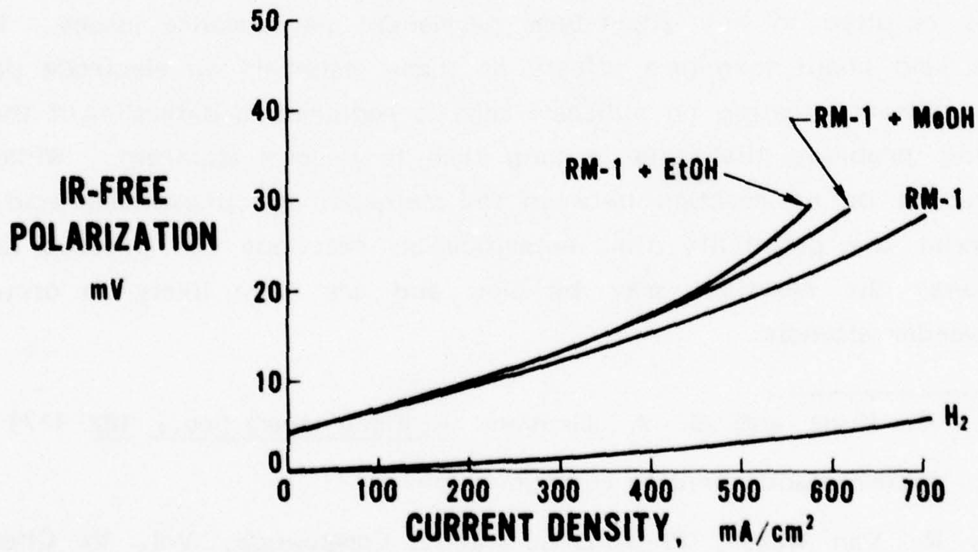


Figure 24. Performance Curves for Alcohol-Containing Fuels

A second major concern addressed in these studies was the likelihood of methanol reacting with concentrated phosphoric acid at 375°F. There is some evidence available that indicates phosphoric acid esterifies isopropanol under similar conditions.[2] A literature search was done to see if this reaction is in fact possible, but no specific references were uncovered except for vague statements that indicate that direct esterification of alcohols can be carried out at high temperatures with phosphoric acid.[3] In the case of methanol, there was no indication during our short testing times that any reaction was occurring. It seems unlikely that this reaction would occur appreciably since the expected product, monomethyl phosphate $CH_3OP$ (o) $(OH)_2$, is very unstable.[3, p 582] A direct experiment to check this was not done since product separation and chemical analysis for esters was of a complexity beyond the scope of this preliminary work. Although an esterification reaction involving methanol seems unlikely, this question should be addressed in the future, particularly in those cases involving higher-order alcohol impurities.

Conclusions. Methanol concentrations of 20% in simulated reformer effluent cause only a slight initial performance loss on fuel cell anodes operated in concentrated phosphoric acid at 375°F. Ethanol concentrations of 6% also cause only a slight initial performance loss under these conditions. Neither of these alcohols resulted in any short-term permanent performance losses. Nothing can be said about long-time effects of these materials on electrode performance; endurance testing on subscale cells is required to determine if there are poisoning problems that take a long time to become apparent. While there appeared to be no reaction between the methanol and phosphoric acid, there does exist the possibility that esterification reactions can proceed at these conditions; the reactions may be slow and are more likely to occur with higher-order alcohols.

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1. H. R. Kunz and G. A. Gruver, J. Electrochem Soc., 122 1179 (1975)

2. T. Westmoreland, private communication.

3. J. R. Van Wazer, Phosphorus and Its Compounds, Vol. VI Chemistry, Interscience, New York, 1966; P.570.

SUBTASK 3.0, CONCEPTUAL DEFINITION OF POWER PLANT SYSTEMS

A. Premix Fuel Power Plant

1. SYSTEM SELECTION. A system using an air-cooled stack with air recycle for cell temperature control was selected from among four candidate systems. Two of the systems utilized air-cooled stacks and two used a dielectric liquid for cooling. The criterion used in making the selection was the system's potential for meeting the Army's primary requirements of weight, volume, fuel consumption, and reliability.

The system selected, shown in Figure 25, uses cell process air for cooling as well as for supplying oxygen for consumption. A portion of the hot cell exhaust air is mixed with the cold inlet air to maintain the desired cell temperature. The fuel processing subsystem consists of a burner, vaporizer, and reformer. Energy to vaporize and reform the fuel is provided by burning excess hydrogen in the fuel cell anode exhaust. The other air-cooled stack system, Figure 26, uses a regenerative heat exchanger to transfer heat from the cell exhaust air to the inlet air. Cell temperature is controlled by modulating the flow of cold inlet air through the heat exchanger. The fuel processing subsystem is the same as in the previous system.

The dielectric-cooled stack system, shown in Figure 27, uses a closed coolant loop with an ambient-air-cooled heat exchanger and a cooling air fan to reject cell waste heat. The fan is cycled on and off to maintain desired cell temperature. The fuel processing subsystem is identical to that of the air-cooled stack systems.

The fourth system considered, shown in Figure 28, also uses a dielectric coolant to remove cell waste heat. It differs from the previous system in that the dielectric coolant supplies heat to vaporize and reform the fuel. This system has the potential for the highest thermal efficiency since it utilizes cell waste heat to supply a portion of the energy necessary to process the fuel.

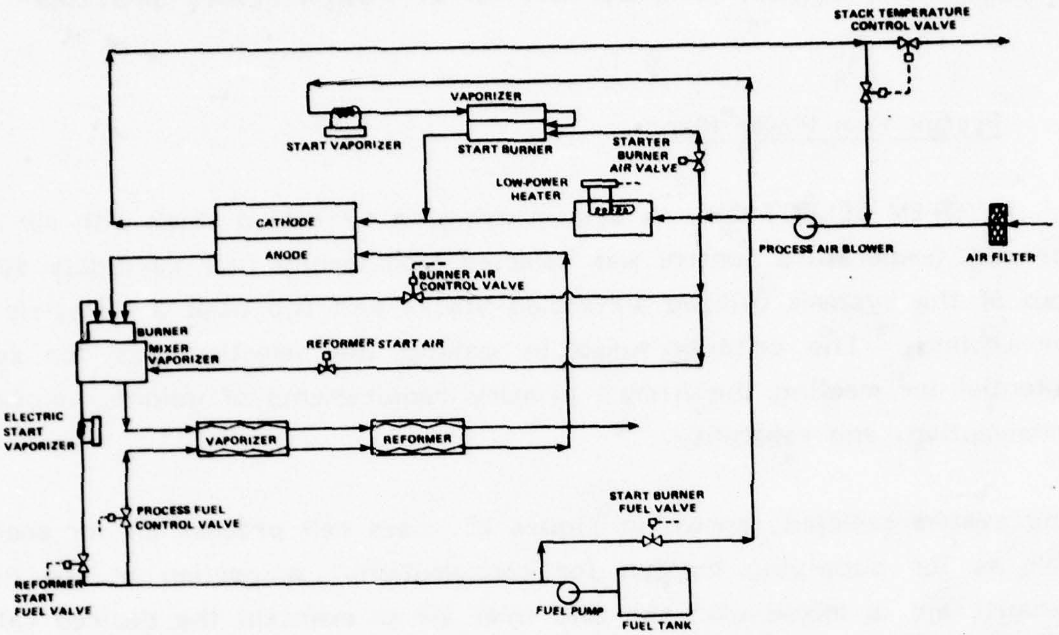


Figure 25. Process Air-Cooled Power Plant System

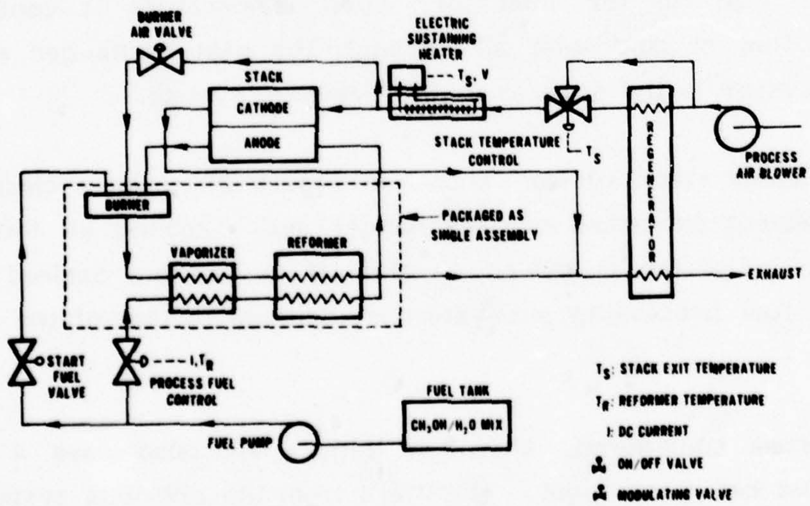


Figure 26. Process Air-Cooled Stack with Regenerator

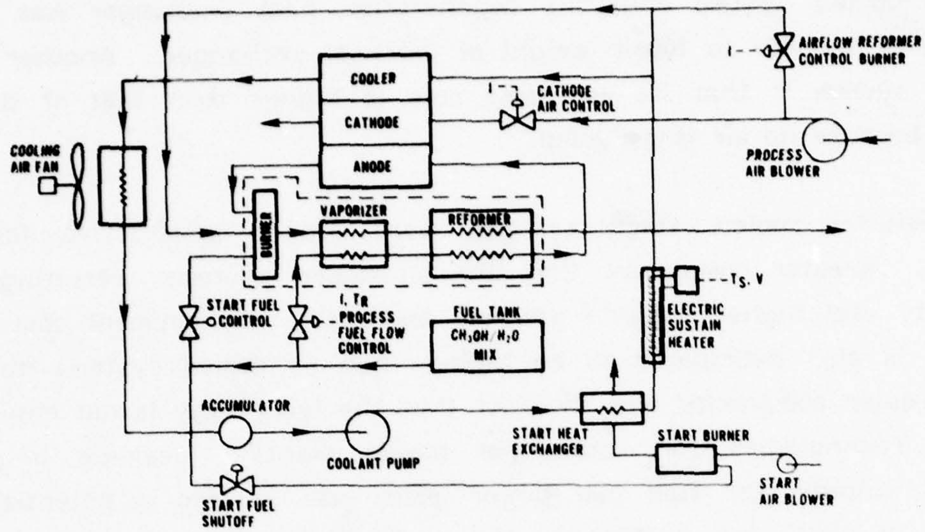


Figure 27. Liquid-Cooled Stack with Low-Temperature Coolant

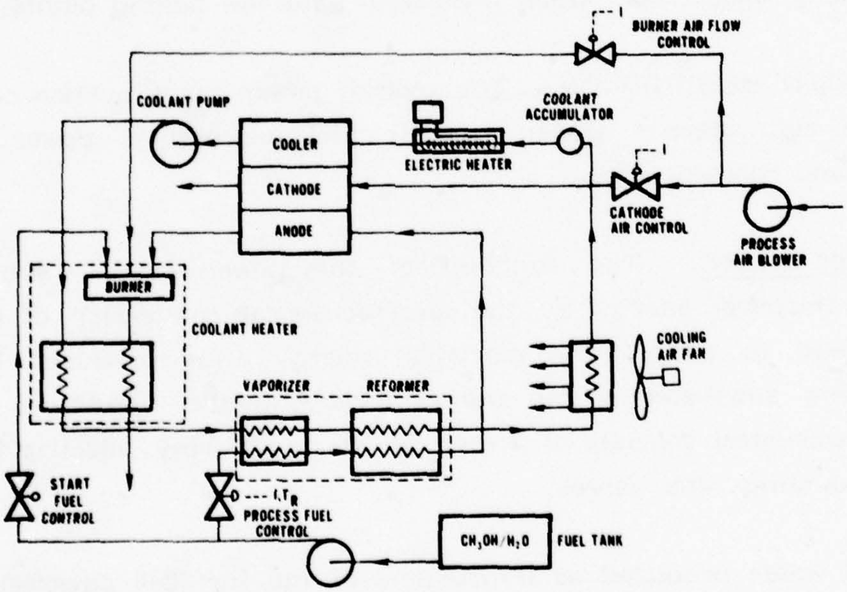


Figure 28. Liquid-Cooled Stack with High-Temperature Coolant

The air-cooled system with the regenerative heat exchanger was eliminated because of the 60- to 100-lb weight of the heat exchanger. Another drawback of this system is that its acid loss rate is higher than that of the recycle system because no air is recycled.

The dielectric-cooled stack systems were found unattractive for several reasons: greater complexity than the air-cooled systems, resulting in lower reliability and higher weight, volume, and cost. Development costs of these designs is also anticipated to be higher than air-cooled systems due to both their greater complexity and the fact that the technology is not envisioned by United Technologies for commercial power plants. Leakage of dielectric coolants suitable for fuel cell power plant use is also a potential problem because of their low surface tension. The problem is compounded by the necessity to pressurize the coolant to prevent its boiling at cell operating temperature. The requirement to start up from -65°F requires the use of low-viscosity dielectrics, which invariably have low boiling points.

2. SYSTEM DESCRIPTION. The overall power plant system can be divided into five subsystems: power section, fuel processing, power conditioning, control, and reactant supply.

2.1 Power Section. The function of the power section subsystem is to produce electrical energy by the electrochemical conversion of hydrogen and oxygen and to supply the electrical energy thus produced to the power conditioning subsystem within the required interface conditions. The power section subsystem consists of a fuel cell stack assembly, electric heaters, start burner, ducting, and valves.

Heat and water produced as byproducts of the fuel cell chemical reaction are removed from the cells by the process air stream, which also supplies oxygen to the cathodes. A portion of the hot stack exit air is mixed with the inlet air to maintain the desired cell temperature. This is accomplished by the stack temperature control valve acting on a temperature error signal. This error

signal is the difference between the measured stack exit air temperature and a predetermined temperature vs. current schedule (see Figure 29), designed to maintain an average cell temperature of 350°F. Figure 30 shows the percent recycle (recycle flow/total flow x 100) as a function of current and ambient temperature. Recycle flow increases with the decreasing current and ambient temperature, but it is limited to a maximum of 99% of the total flow to ensure an adequate supply of oxygen for the cell reaction. Additional energy, if required to maintain cell temperature, is supplied by the electric heaters in the stack inlet air stream. Up to 450 watts of heater power may be supplied by three heater elements in 150-watt increments. The heaters are also activated to prevent stack output voltage from exceeding the maximum allowable inverter input voltage (60 Vdc). This is necessary only for new cells operating below a net power of 600 watts. The stack's performance characteristics initially, and at 6,000 hours life are shown in Figure 31. Heatup of the fuel cell stack is accomplished by flowing hot air obtained by mixing ambient air with the start burner exhaust through the cathode flow fields. The start burner uses the methanol-water premix fuel vaporized for efficient combustion. The fuel mixture is initially vaporized by an electric heater and subsequently by the hot burner exhaust. The start burner fuel flow is modulated to maintain a constant stack inlet air temperature (400°F) regardless of the variations in air flow caused by the wide range (-65 to 125°F) of ambient temperature.

2.2 Fuel Processing. The function of the fuel processing subsystem is to provide the necessary flow of hydrogen-rich gas to the power section within the required interface conditions. The fuel processing subsystem consists of a burner, fuel vaporizer, catalytic reformer, piping, and valves. The burner, vaporizer, and reformer are packaged in a single assembly for compactness and light weight and to minimize heat loss. Energy to vaporize and reform the fuel is provided by burning the excess hydrogen exiting from the power section. Process fuel flow is controlled by reformer temperature and power section current by means of the process fuel control valve. The power section current signal is used to provide rapid fuel flow response to load changes,

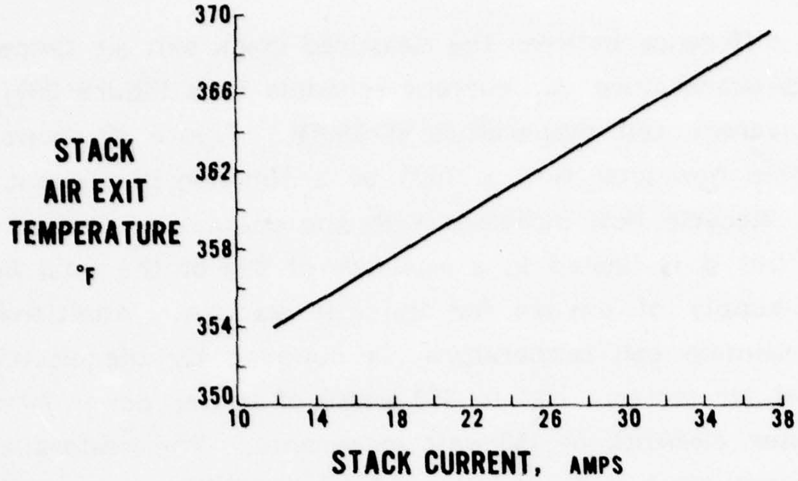


Figure 29. Stack Current versus Exit Air Temperature

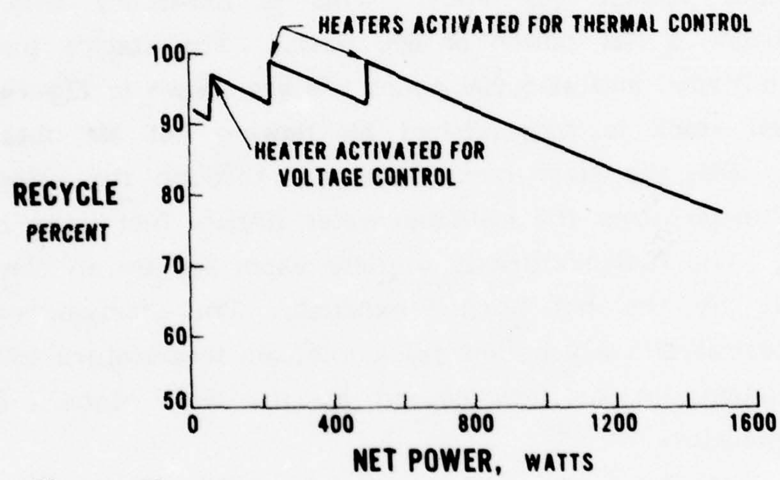


Figure 30. Stack Current versus Percent Recycle

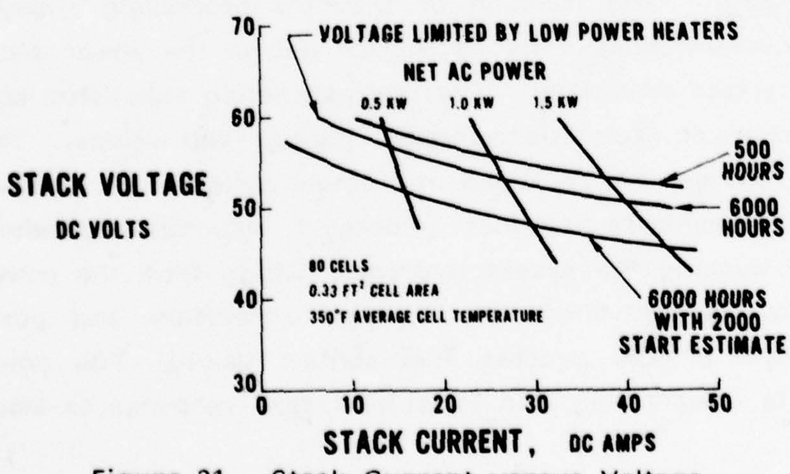


Figure 31. Stack Current versus Voltage

while reformer temperature governs long-term steady-state fuel flow. Figure 32 shows the steady-state fuel flow as a function of power section current. Reformer burner air flow is also controlled by power section current by means of the burner air control valve. This schedule, shown in Figure 33, is designed to provide a constant reformer inlet temperature of 350°F over the entire load range.

Heatup of the reformer assembly is accomplished by burning the vaporized methanol-water mixture in the reformer burner. As in the start burner, an electric heater is used to vaporize the fuel initially, and burner exhaust vaporizes the fuel once the burner is ignited. The fuel processor start fuel flow is controlled by the reformer temperature to ensure a 15-minute startup in cold environments and without overheating the reformer catalyst on a hot day because of reduced burner air flow.

2.3 Power Conditioning. The power conditioning subsystem converts the dc output of the power section to meet the Army's generator set output requirements. These requirements are defined in the Power Conditioner Technology section, 1.C, Page 7.

2.4 Control. The control subsystem provides for automatic startup, shutdown, and unattended operation of the power plant. The control subsystem consists of the automatic control unit and battery charger (single unit), battery, main load contactor, the control and instrumentation panel, sensors

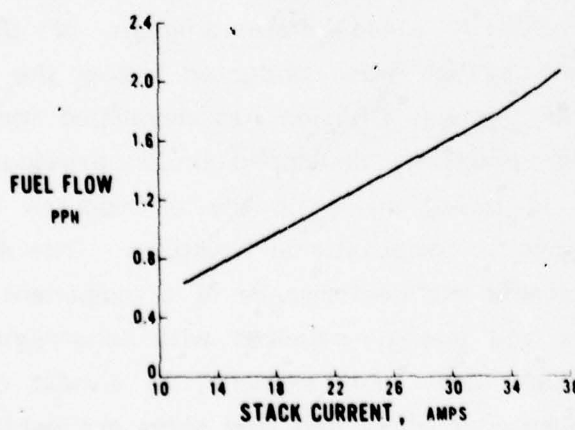


Figure 32. Stack Current versus Fuel Flow

(reformer temperature, stack exit-air temperature, power section current, and voltage), and component drivers. The automatic control unit:

1) provides continuous control of

| | |
|---|---|
| recycle air flow | start burner fuel flow |
| reformer burner air flow | reformer start fuel flow |
| process fuel flow | |

2) provides sequential control of

| | |
|---|---|
| low-power heater | process fuel pump |
| start burner air | start fuel vaporizers |
| reformer start air | ignitors |
| recycle shutoff | main load contactor |
| process air blower | battery load switch |

3) monitors critical system parameters

| | |
|---|---|
| stack exit temperature | power section voltage |
| reformer temperature | power section current |

4) charges battery.

2.5 Reactant Supply. The reactant supply subsystem supplies fuel to the fuel processor subsystem for startup and processing and to the start burner. The reactant supply subsystem also supplies air to the fuel cell stack, start burner, and reformer burner. This subsystem consists of a process air blower, process fuel pump, filters, and plumbing.

3. SYSTEM ANALYSIS. A steady-state analysis of the methanol-water premix-fuel power plant system was conducted using the modular computer program that the Power Systems Division has developed for fuel cell systems analysis. This modular program, developed under previous commercial contracts and activities, is based on a library of modules that are used as necessary to provide specific computational functions. The modules are mathematical models that describe the performance of a component. In general, the models consist of mass and energy balances with constraints imposed by the characteristics of a given unit. For example, in a heat exchanger module, energy and mass balances on the hot and cold sides are performed, the energy transfer from the hot side to the cold side being constrained by the overall

heat transfer coefficient of the particular unit. Modules are not specific to a particular design, and consequently the same module may be used in a variety of applications. Information necessary to define a particular unit is supplied either through specific inputs or through parametric data maps.

No change to the program was necessary to use it for analysis of the Army power plant system.

The reformer was modeled using a standard reformer module to perform the mass and energy balances, and maps that were generated by PSD's reformer design computer program and that define the heat transfer and conversion characteristics of the 1.5-kW methanol reformer design. The vaporizer was modeled as a parallel-flow heat exchanger using the logarithmic-mean-temperature-difference approach. The overall heat-transfer coefficient was assumed to be constant over the flow range. The enthalpy of methanol used in the analysis was obtained from the published literature.[1] The lower heating value of liquid methanol was calculated to be 8585 Btu/lb at 77°F from the heat of formation of methanol vapor and the heat of vaporization. The fuel cell module performs a mass and energy balance using performance maps that define cell voltage as a function of cell current density (Figure 3). Product water and waste heat are removed by the process air stream. The process air blower was assumed to be a constant volumetric flow device, mass flow varying inversely with the blower inlet temperature and directly with pressure.

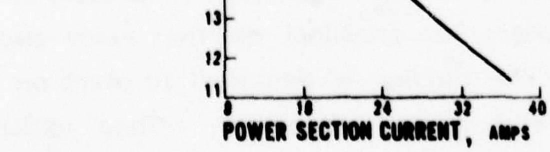


Figure 33.
Schedule of Power Section Current

1. Smith, J.M., Chemical Engineering Progress, Vol. 44, No. 7, p 523 (1948).

Power plant operating characteristics were examined at the extremes and under nominal conditions, i.e., initial cell life, 70°F ambient temperature, and 50% relative humidity. The severest condition for heat rejection occurs at 6000 hours cell life with 125°F ambient temperature, whereas initial cell performance with 65°F ambient temperature is the severest for maintaining required thermal conditions. The system model predicts satisfactory power plant operation over the entire power range for the 6000 hours life requirement to all ambient conditions. Critical system parameters were maintained well within the allowable limits. System flows and temperature are presented in Appendix A.

Station numbers in the tables correspond with those on the system schematic, Figure 25. Satisfactory power plant operation is also indicated with the cell performance level estimated for 2000 startup-shutdown cycles (see Table A-32 in Appendix A).

A lumped heat capacity heatup analysis was performed for both the stack and reformer to determine burner fuel and air flows necessary for a 15-minute startup from -25°F. A similar thermal transient analysis was performed to determine the stack cooldown rate for estimating stack shutdown voltage losses. Results of these studies are presented in Figures 34, 35, and 36.

4. SUBSYSTEM/COMPONENT DESIGN ANALYSIS. The following paragraphs discuss the design analysis of subsystem and components under the topics of Fuel Processor Subsystem, Power Section Components, Control Subsystem, and Reactant Supply Subsystem.

4.1 Fuel Processor Subsystem. The primary component of the fuel processor subsystem is a reformer which contains an annular reactor, burner, and vaporizer, shown in Figure 37. The overall dimensions are 13 inches in diameter and 16.5 inches high. The package weight and volume are 30 lb and 1.26 $ft^3$. The burner and vaporizer are located inside the reactor to minimize heat loss. As Figure 37 shows, process gas and burner gas are in a co-flow configuration. Analysis has shown that this arrangement is preferred since the hottest burner gas is located where the chemical reaction rates and heat transfer requirements are highest. The burner is designed to start on liquid fuel vaporized by a small electrically heated vaporizer. Once ignition is achieved, heat for fuel vaporization is picked up from the burner flame and no further electrical energy is required.

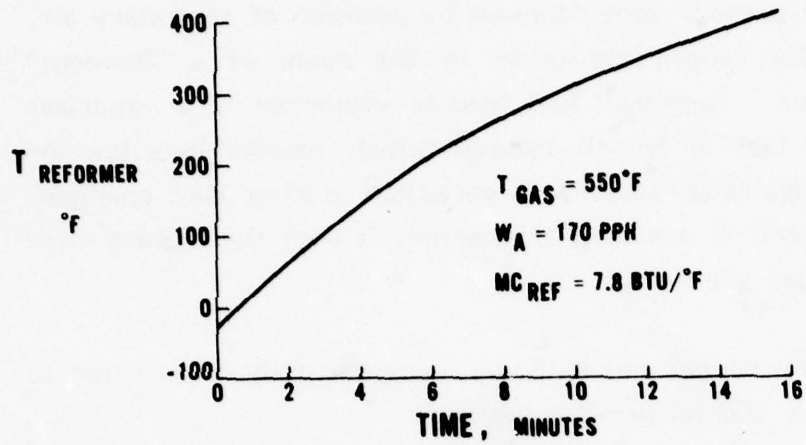


Figure 34.
Vaporizer-Reformer Heatup

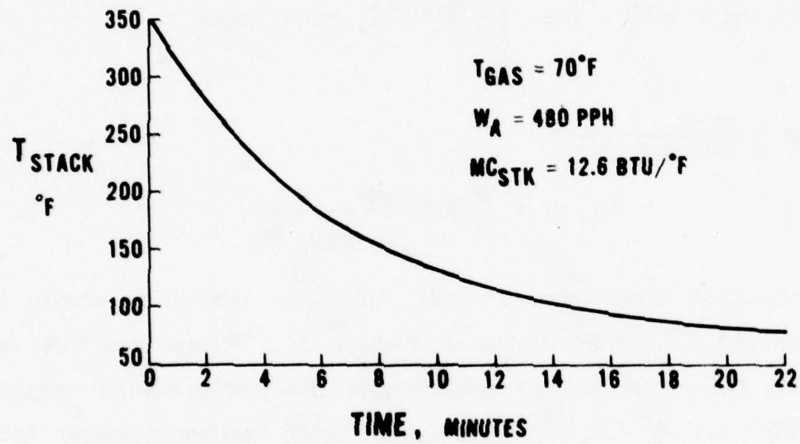


Figure 35.
Stack Cooldown

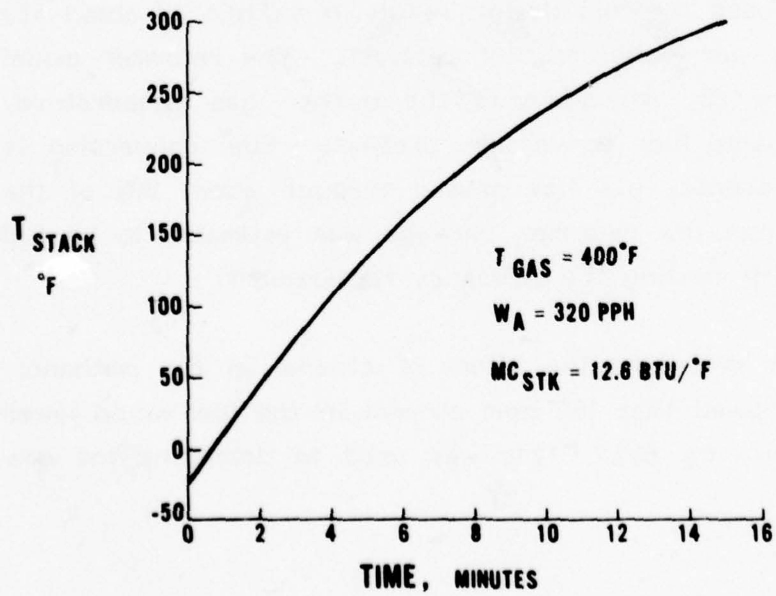


Figure 36.
Stack Heatup

Burning is done in a "hot" primary zone followed by addition of secondary air. This primary zone provides relight capability in the event of a "flameout" during rapid load transients. Reformer fuel feed is vaporized in a vaporizer coil consisting of about 6 feet of ¼-inch tubing, which results in a low inventory of liquid fuel to minimize steam/fuel variations during load changes. High heat transfer to the coil is achieved by heating it with the highest temperature (1900°F) burner gas available.

The intrinsic activity of the copper catalyst was experimentally determined to be related to temperature by the following equation:

$$k\ CH_3OH = 5280.\ \exp\left(\frac{-18,513}{RT}\right)\ \text{cal/g mole}$$

where k is expressed in $\frac{\text{g mole}}{\text{g cat sec atm}}$

$$T = {}^{\circ}K,\ R = 1.986\ \frac{\text{cal}}{\text{g mole }{}^{\circ}K}$$

The catalyst activity equation was used in our reformer model to study the performance of the proposed reformer shown in Figure 37. These studies confirmed that the proposed reformer design would meet the performance requirements of 100% fuel conversion at 75% efficiency with pure methanol-water feed. Catalyst bed dimensions chosen for this design result in a THSV of about 580 $ft^3$/hr of hydrogen (STP) per cubic foot of catalyst. The reformer model output is shown in Figure 38, which shows the burner gas temperature, process gas temperature, and fuel conversion profiles. Fuel conversion is essentially 100% after the process gas has passed through about 80% of the catalyst bed. Heat loss from the reformer package was estimated to be 600 Btu/hr and is consistent with meeting the efficiency requirement.

Studies were also done to determine the effect of ethanol in the methanol. Laboratory measurements showed that 100 ppm ethanol in the fuel would lower the intrinsic catalyst activity by 60%. This was used to determine the new

fuel conversion profile, assuming the same wall temperature as was used for pure methanol. A comparison of fuel conversion profiles for pure methanol and methanol/100 ppm ethanol are shown in Figure 39. The depressed fuel conversion profile results in about 2% of the fuel passing through the reactor unreacted. The next study was to determine if the fuel conversion profile could be improved significantly by a modest increase in wall temperature. The results of this study are shown in Figure 40. It was found that a 50°F increase in wall temperature would result in the same fuel conversion profile as for pure methanol, as Figure 40 indicates. This increase in temperature is within the catalyst allowable limits.

4.2 Power Section Components. The power section subsystem consists of a fuel cell stack, electric heaters, start burner, ducting, and stack temperature control valve. The stack, which consists of 80 cells of 0.33 $ft^2$ of active area each, weighs 54 pounds and has a volume of 2.52 $ft^3$ (including insulation). Stack dimensions with insulation are 18.5 x 11.5 x 20.5 inches. The cell planform consists of a 4 x 12-in. catalyzed electrode surface with a seal border. The seal border is an uncatalyzed extension of the electrodes and matrix to provide sealing against external reactant leakage.

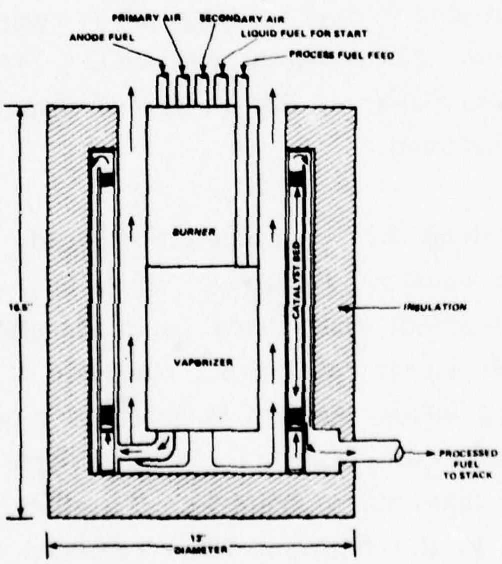


Figure 37. Reformer Subsystem

An overall power plant efficiency of 30% (fuel consumption of 1.33 lb/kWhr) was used as the basis for determining total cell area. The 30% goal efficiency was selected as a result of a trade study presented in Figure 41, which indicated that a significant increase in stack size would be required for higher efficiencies. Given an overall efficiency goal, there is still some latitude in selecting cell area and number of cells because of the inverter efficiency dependence on input voltage, by which a higher input voltage (up to a limit) provides higher inverter efficiency. Figure 42 shows how this dependence influences stack size and gross dc power turndown. The smallest stack that would meet the power plant efficiency goal at rated power is one whose output voltage at rated power was equal to the maximum allowable inverter input voltage (therefore maximum inverter efficiency). However, since fuel cell voltage increases with decreasing load, the stack dc load would have to remain constant to avoid exceeding the maximum allowable inverter input voltage, thus resulting in poor part-power fuel consumption. The minimum gross power necessary to keep stack voltage below the maximum allowable can be reduced by lowering stack voltage and consequently inverter efficiency. To compensate for the reduced inverter efficiency, cell efficiency is increased by increasing total cell area. The impact of cell area on minimum gross power is shown in Figure 42. Because heaters are required at low powers for maintaining cell temperature, no further benefit in fuel consumption is realized by reducing the minimum gross power below approximately 600 watts. The cell area corresponding to a minimum gross power of 620 watts (corresponds to 350 watts net at beginning of life) was selected.

Cell geometry was determined by an optimization study aimed at achieving minimum stack weight and volume. Results of the study are shown in Figure 43. The height of the reactant flow fields (and therefore stack volume) is strongly dependent on cell aspect ratio, i.e., the ratio of a cell's width to its length. Since cathode and anode reactant flowpaths are perpendicular to each other, a deviation in aspect ratio from 1:1 will necessitate an increase in field height on one side and a decrease in height on the other to maintain constant pressure drop. Because of the high air flows required for cooling, a short

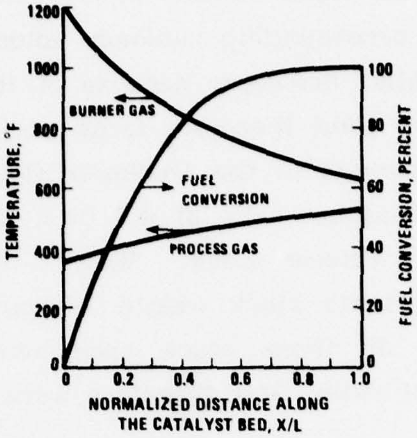


Figure 38. Reformer Output

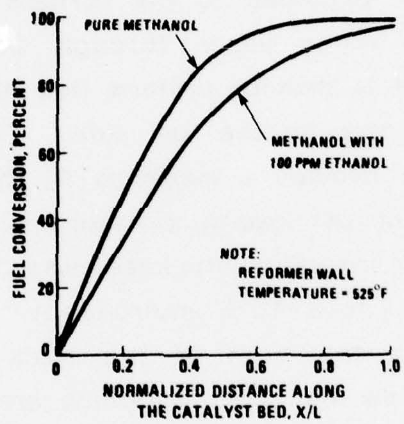


Figure 39. Comparison of Fuel Conversion Profiles

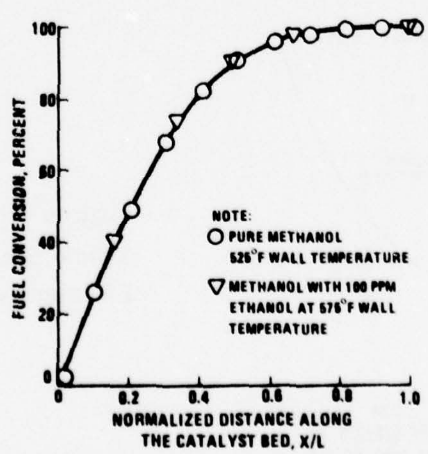


Figure 40. Fuel Conversion at Two Temperatures

air flowpath with shallow air fields results in the minimum total (air plus fuel) flow channel height and corresponding minimum volume. Stack weight is also affected by cell aspect ratio, however; because of the relatively dense edge-frame, a large aspect ratio (and therefore large perimeter) configuration more than offsets the weight savings in the shallower flow fields. It can be seen from Figure 43 that a cell aspect ratio of 3:1 (4 x 12 cell active area) results in a minimum weight and volume stack. Weight of the repeating elements shown in Figure 43 represents stack weight without endplates and reactant manifolds. The weights of these stack components are not significantly affected by the cell aspect ratio, and therefore were not included in the optimization study.

The reactant manifolds are extended to the corners of the stack to minimize absorption of atmospheric water vapor through the seal edge area. The reactant manifolds designed to provide uniform flow distribution are 1 in. deep on the air side and ½ in. deep on the fuel side. The 1-in. thick honeycomb endplates were selected to provide a maximum 4% differential in cell loading pressure. An average of 66 psi loading pressure is applied by means of four ¼-in. diameter bolts. Stack insulation thickness was designed to limit heat loss to a maximum of 1000 Btu/hr to a -65°F environment. Two inches of fiberglass insulation are used around the sides of the stack and 1 inch at top and bottom. Anode reactant flow field and manifolds are designed for 0.4 in. of $H_2O$ pressure drop at the maximum rated flow (3.67 pph). Air flow field and

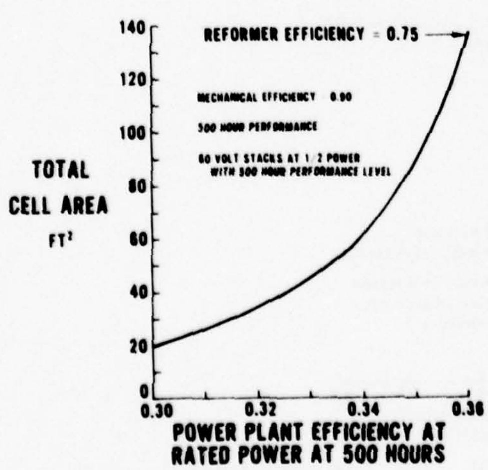


Figure 41.
Stack Size versus Reformer Efficiency

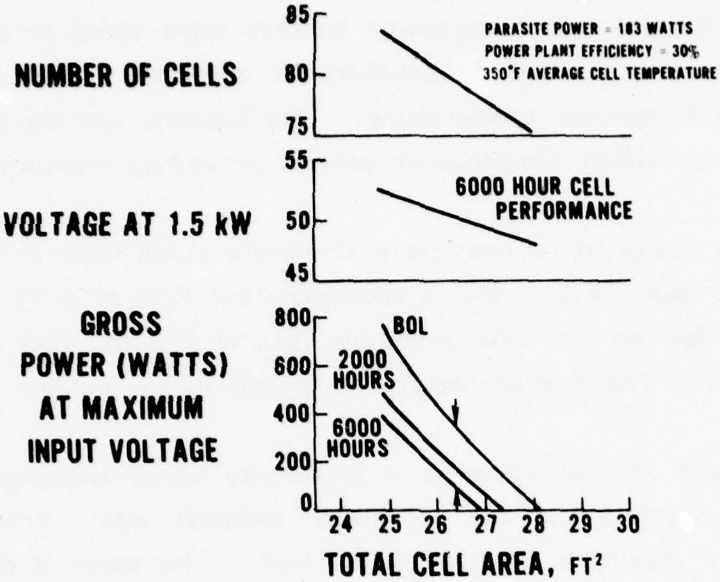


Figure 42. Summary of Cell Area Study

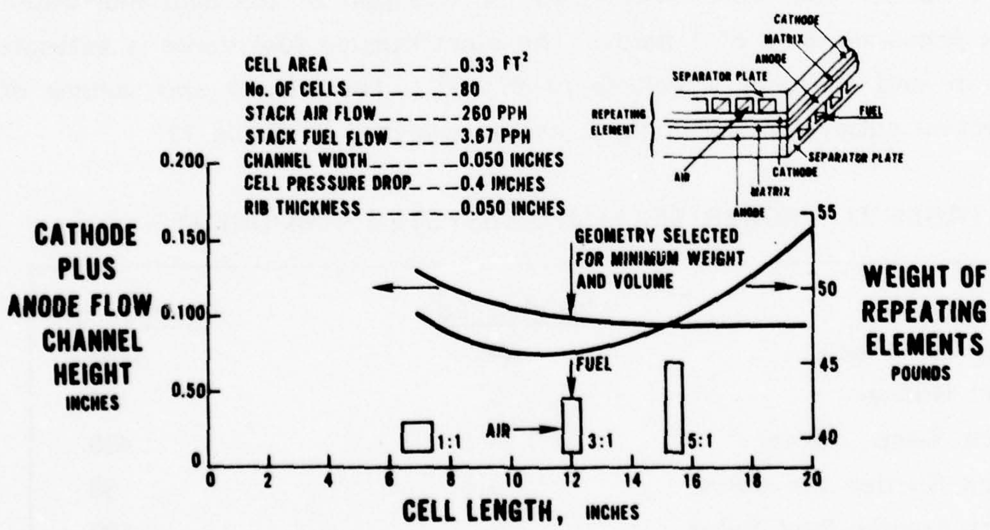


Figure 43. Cell Geometry Study, Air-Cooled Stack

manifolds were designed for 0.5 in. $H_2O$ stack pressure loss at the start air flow (320 pph) conditions. The low-power heaters were sized to provide 450 watts of energy to maintain cell temperature at zero net power with initial performance and -65°F ambient temperature. The heaters can be activated in 150-watt increments for either temperature control or voltage limiting.

The start burner is designed to provide a 15-minute stack heatup from -25°F. The burner uses 45 pph of air and a maximum fuel flow of 6.21 pph. The burner is designed for an air side pressure loss of 0.2 in. $H_2O$ and a fuel side loss of 2.5 psid. The burner weighs 4 lb and has a volume of 160 $in^3$.

The stack temperature control valve is a three-way valve allowing from 0 to 320 pph air flow through either the recycle or exhaust legs. Pressure drop through either leg at maximum flow is 0.5 in. $H_2O$. The valve is estimated to weigh 4.5 lb with a volume of 450 $in^3$ and draws 20 watts of power. The start burner air valve is designed for a flow of 45 pph at a pressure drop of 0.1 in. $H_2O$. The valve is estimated to weigh 3.5 lb with a volume of 30 $in^3$. The start burner fuel valve was sized for 6.2 pph of the methanol-water mix flow at a pressure drop of 1 psid. The start burner fuel valve is estimated to weigh 3 lb and to have a volume of 97 $in^3$. The weight and volume of the power section subsystem components are summarized in Table 11.

TABLE 11. POWER SECTION SUBSYSTEM COMPONENTS

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Fuel Cell Stack | 54 | 4355 |
| Start Burner | 3 | 160 |
| Stack Temp. Valve | 4.5 | 450 |
| Stack Burner Air Valve | 3.5 | 30 |
| Start Burner Fuel Valve | 3 | 100 |
| Electric Heaters | 1 | - |
| Ducting | 1 | 500 |
| Total | 70 | 5595 |

4.3 Control Subsystem. The control subsystem consists of the automatic control unit and battery charger, battery, main load contactor, control and instrumentation panel, three temperature sensors, and component drivers. The control unit is estimated to weigh 7 lb and to have a volume of 0.1 $ft^3$. The unit includes the controller, battery charger, and drivers. The drivers are solid-state switches that actuate system components in response to input signals from the control logic. The design of the control unit is based on single chip microprocessors using metal-oxide-semiconductor (MOS) technology and is similar in concept to the microprocessor control unit used in PSD's 40-kW on-site power plant. MOS technology offers advantages of high circuit impedance, extremely low circuit power consumption, high electrical noise immunity, and high functional density on the integrated circuit chip.

The battery power supply selected consists of 36 type HR-4 silver-zinc cells manufactured by the Yardney Electric Corp. The battery pack designed for two consecutive startup and shutdown cycles weighs 8 lb. Table 12 summarizes the energy required for startup and shutdown.

TABLE 12. BATTERY POWER AND ENERGY REQUIREMENTS

| | | Energy, watt-hours | |
|---|---|---|---|
| | Power | Start | Shutdown |
| Start Air Valve | 10 | 2.5 | 0 |
| Process Air Blower | 80 | 20 | 20 |
| Process Fuel Pump | 5 | 1.3 | 0 |
| Reformer Start Air Valve | 10 | 2.5 | 0 |
| Start Burner Fuel Valve | 3 | 1 | 0 |
| Reformer Start Fuel Valve | 3 | 1 | 0 |
| Automatic Control Unit | 20 | 5 | 5 |
| Electric Start Vaporizers | 1500 | 50 | 0 |
| Total | 1631 | 83.3 | 25 |

Energy required for two startup-shutdown cycles: 217 watt-hours

4.4. Reactant Supply Subsystem. The reactant supply subsystem consists of the process fuel pump and filter, process air blower, air filter, and plumbing. Both the process air blower and fuel pump flows and pressure drops were determined by the flows required for a 15-minute startup from -25°F. The required blower flow is 95 scfm at a pressure rise of 1.2 in. $H_2O$. The blower parasite power is estimated to be 80 watts. The process fuel pump, which is similar to the PC14 fuel pump, delivers 11 pph of methanol-water mix at a pressure rise of 3.5 psid. The pump draws 5 watts of parasite power. Subsystem weight and volumes are summarized in Table 13.

TABLE 13. REACTANT SUBSYSTEM WEIGHT AND VOLUME SUMMARY

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Process Air Blower and Ducting | 5 | 310 |
| Fuel Pump and Plumbing | 3 | 75 |
| Total | 8 | 485 |

5. POWER PLANT DESCRIPTION. Nine key parameters were selected as the basis for determining the viability of a fuel cell power plant as a power source for Army field service. These parameters, together with the purchase description requirements and the design values for the dc generator (Mode IV set) are listed in Table 14. The design exceeds the weight and volume goals by 17%. Specific fuel consumption, however, is 40% better than required. A tradeoff can be made between these parameters to reduce weight and volume to meet the purchase description requirements. Figure 44 shows the effect of stack weight on specific fuel consumption. The weight of the dc set could conceivably be reduced to meet the 150-lb requirement by reducing the stack weight from 54 to 29 lb, thus increasing fuel consumption from 1.22 to 1.37 lb/kWhr. Further study is required to investigate the impact of the higher heat flux on cell cooling and the increased fuel flow on reformer design prior to a final decision.

The overall power plant weight is based on the subsystem weight shown in Table 14. The structure weight was estimated using PC14 component-to-

structure weight ratio. The 7-ft$^3$ power plant volume is a result of the packaging arrangement represented by the attached layout, Figure 45.

The ac power plant is 46 lb heavier and 0.6 ft$^3$ larger in volume than the dc power plant because of the ac inverter. Specific fuel consumption is also higher: 1.33 vs. 1.22 lb/kWhr, because of the lower inverter efficiency.

The power plant's MTBF was established based on the reliability model shown in Figure 46. Individual component failure rates were drawn from References 1, 2, and 3 and were increased by a factor of five to compensate for the rigors of the portable ground equipment environment.

The effect of the 2000 startups and the severe ambient temperature requirements on stack performance are difficult to assess with the limited data available. However, a cell voltage loss of 0.060 volt was estimated as the effect of 2000 startup-shutdown cycles. This estimate was calculated based on the stack heatup and cooldown curves and a semi-empirical correlation for the effects of startup and shutdown conditions, *i.e.*, *operating potential* and cell temperature on performance. The calculated value was doubled because of the lack of data for such a large number of repeated starts. In commercial applications the number of starts and shutdowns is limited, and auxiliary equipment is used to passivate the cell environment during startup and shutdown. The Army's requirements for light weight and rapid start preclude the use of these means for reducing losses.

TABLE 14. PREMIXED FUEL POWER PLANT WEIGHT AND VOLUME SUMMARY, DC POWER PLANT

| Subsystem | Weight, Lb | Volume, Ft$^3$ |
|---|---|---|
| Power Section | 70 | 3.24 |
| Fuel Conditioner | 43 | 1.58 |
| Control | 22 | 0.25 |
| Reactant Supply | 10 | 0.32 |
| Power Conditioner | 14 | 0.38 |
| Structure | 16 | - |
| Total | 175 | 5.77 |

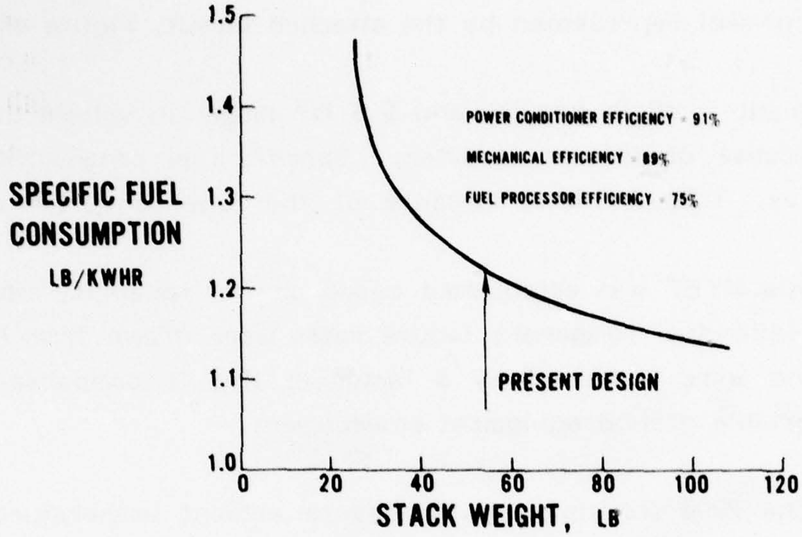


Figure 44. Stack Weight versus Fuel Consumption

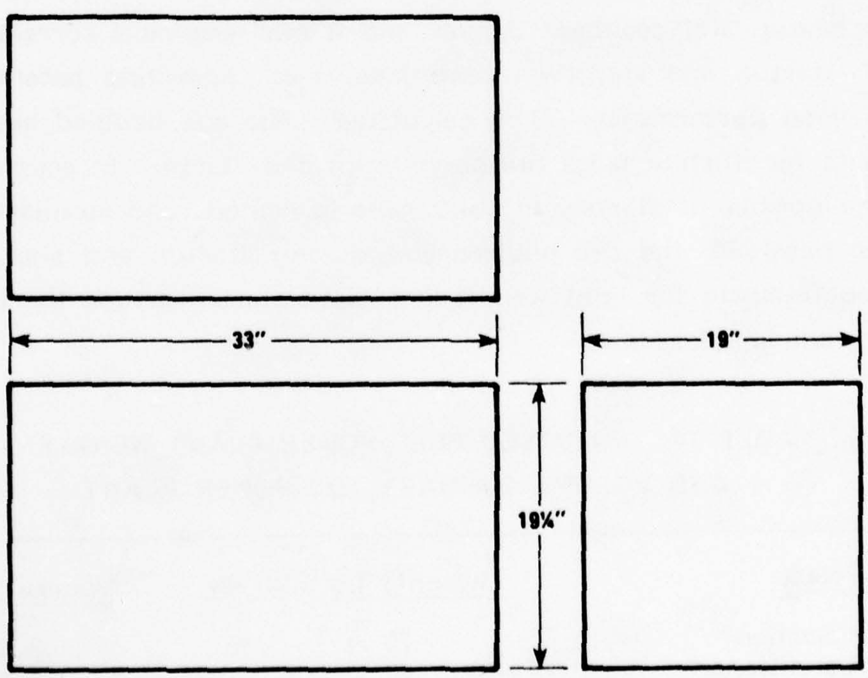


Figure 45. Power Plant Layout Drawing

NOTE: The engineering drawing from which Figure 45 was drawn is bound inside the back cover of this report.

6. IMPACT OF IMPROVED TECHNOLOGY. Several technology advancement programs are under way at PSD. Although these programs are specifically aimed at improving the position of fuel cells in the commercial power plant market, the advancements achieved in these programs will also enhance the primary characteristics of the 1.5-kW Army methanol power plant. Two investigations that may directly benefit Army power plants are:

(1) A catalyst activity improvement program aimed at increasing cell performance by 30 millivolts over and above the 1980 performance projection. This is a coordinated effort being carried out at PSD and several commercial laboratories. A 30-millivolt increase in cell performance would reduce the power section weight by 25%, and

(2) Technology efforts aimed at gaining a better understanding of the effects of multiple start/shutdown cycles and low-temperature storage. This may permit definition of cell and electrode configurations that exhibit reduced start/shutdown performance degradation under military operating conditions. This improvement could reduce stack weight and/or other subsystem weight.

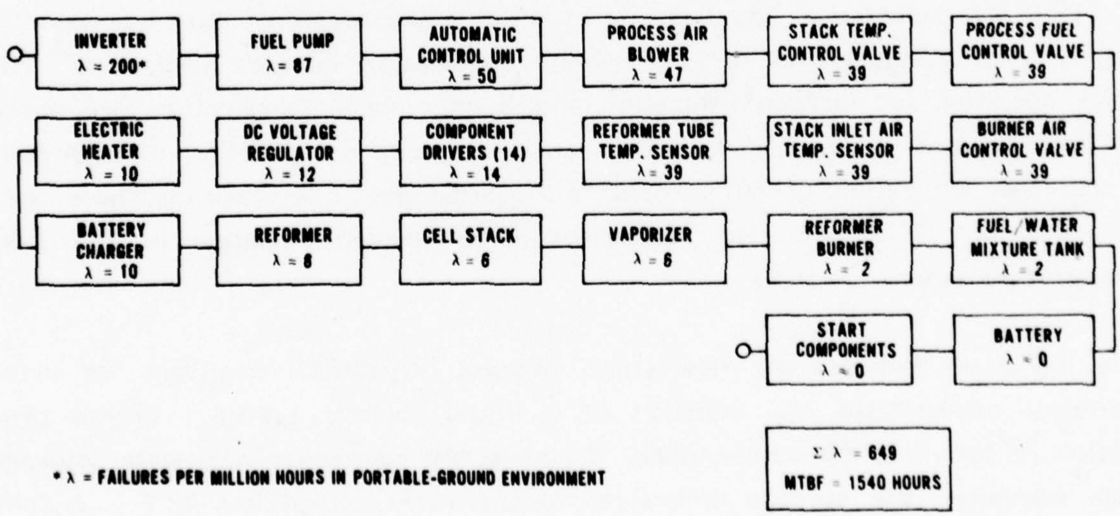


Figure 46. Reliability Model for Air-Cooled 1.5-kW Methanol Power Plant

## B. Power Plant with Water Recovery

1. WATER RECOVERY APPROACH AND SYSTEM SELECTION. To permit the use of only methanol as a power plant fuel, a water-recovery system must be added to supply the water required for the fuel processor. The addition of water recovery required three major modifications to the premix system. These were: addition of a water recovery system, a liquid coolant system for stack thermal management, and freeze protection.

The system with water recovery is shown in Figure 47. Byproduct water from the fuel cells and fuel processor burner is condensed from the combined streams by an air-cooled condenser. The condenser exit dewpoint necessary to recover the required fuel processor water depends on the amount of non-condensibles present in the exhaust stream, i.e., condenser inlet dewpoint or start of condensation temperature. Figure 48 shows this relationship in terms of cell oxygen utilization and burner flame temperature rather than inlet dew-point or air flows. The maximum dewpoint achievable within the specified limits of 128°F precludes the possibility of self-sustaining water recovery on a 125°F day with any reasonable-size condenser. Units for commercial power plants are generally designed for a 5°F temperature difference, but for a portable power plant a larger differential is desirable. An ambient temperature of 115°F was selected as the basis for the condenser design. Surplus water is stored in a storage tank for use when consumption exceeds recovery. The limits specified for oxygen utilization and burner flame temperature are based on practical design limitations. To ensure adequate oxygen flow to each cell, a maximum utilization of 60 percent is recommended. A maximum flame temperature of 1900°F is also recommended to prevent damage to the low-temperature reform catalyst.

The low stack process air flow (high oxygen utilization) required for water recovery necessitates the addition of a liquid cooling system. Freeze protection is provided by automatically draining the condenser and water storage tank whenever the storage tank water temperature approaches 32°F. A tank containing the correct mixture of water and methanol is used to supply the fuel and water required during startup in cold weather.

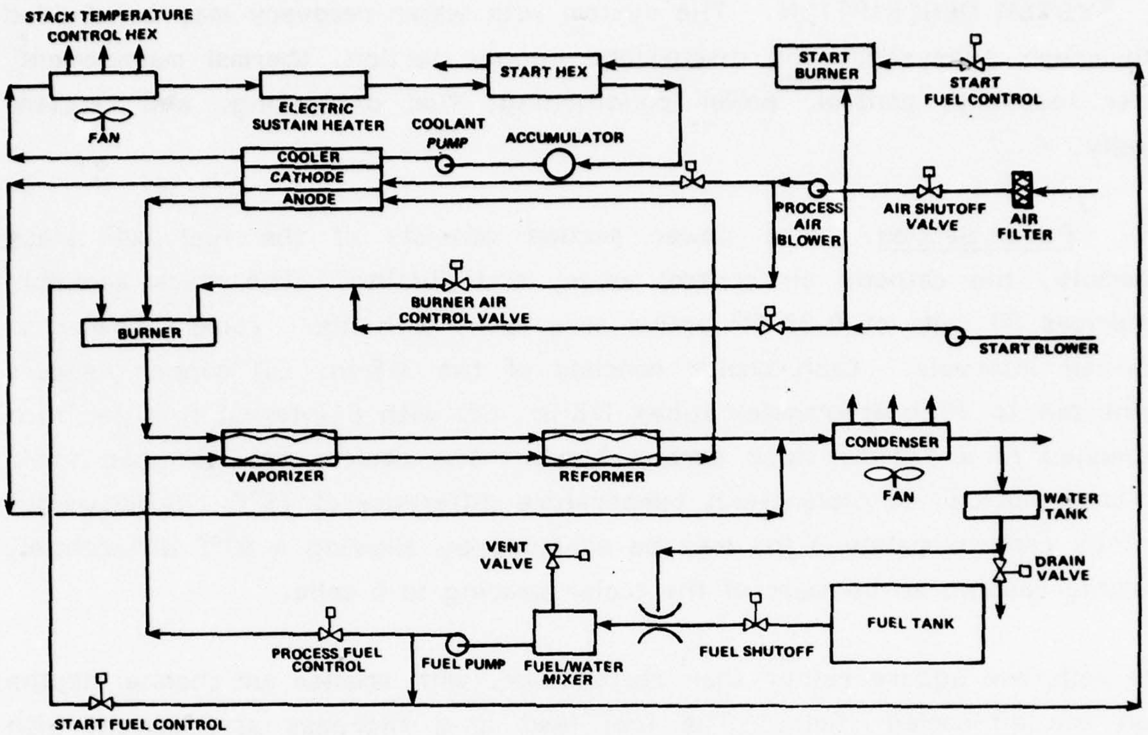


Figure 47. Power Plant System with Water Recovery

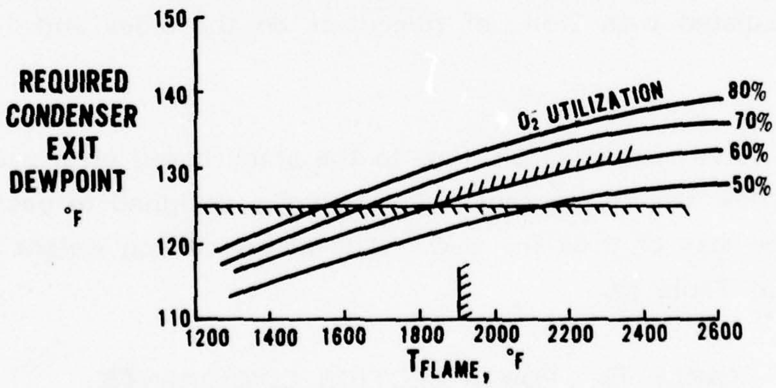


Figure 48. Required Condenser Exit Dewpoint for Self-Sustaining Water Recovery

2. SYSTEM DESCRIPTION. The system with water recovery may be divided into seven subsystems for discussion: power section, thermal management, water recovery, control, power conditioning, fuel processing, and reactant supply.

2.1. Power Section. The power section consists of the fuel cell stack assembly, the cathode air control valve, and ducting. The stack assembly comprises 80 cells of 0.33 $ft^2$ active area each, with liquid coolers spaced at five-cell intervals. Each cooler consists of two 3/8-in. OD copper headers connected to 10 heat-transfer tubes 1/8-in. OD with 6 internal fins per inch embedded in a 1/8-in. thick carbon block. The coolers are designed for a maximum hot-cell to coolant-exit temperature difference of 75°F. Some weight savings (approximately 3 lb) may be achieved by allowing a 90°F differential, possibly causing an increase of the cooler spacing to 6 cells.

The cells are square rather than rectangular, with smaller air channel depths than the air-cooled stack. The fuel feed is a two-pass arrangement with adjacent inlet and exit manifolds on the same end and a turnaround manifold on the opposite end. The fuel inlet manifold and exit manifolds are 1.5 in. deep. The air flow is a one-pass sweep. Air inlet and exit manifolds are 1 in. deep. The stack is insulated with 2 in. of fiberglass on the sides and 1 in. on top and bottom.

The cathode air valve modulates air flow to the stack based on a predetermined schedule of air flow vs. dc current. The valve is designed to pass 15 pph of air at a pressure loss of 0.65 in. $H_2O$. The power section weight and volume are summarized in Table 15.

TABLE 15. POWER SECTION COMPONENTS

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Stack (without coolant) | 64 | 4510 |
| Cathode Air Valve | 3 | 23 |
| Ducting | 1 | 100 |
| Total | 68 | 4633 |

2.2. Thermal Management . The function of the thermal management subsystem is to maintain the desired cell thermal conditions. The thermal management subsystem consists of a dielectric coolant, coolant circulating pump, air-cooled waste-heat heat exchanger, cooling air fan, coolant accumulator, start heat exchanger, start burner, and low-power electric heaters.

FC-43, an inert fluorocarbon liquid manufactured by the 3M company, was selected for the coolant because of its relatively low viscosity at low temperatures (pour point $< -80°F$) and fairly high boiling point (345°F). It is also nonflammable, resistant to chemical attack, and essentially nontoxic. FC-43 has one undesirable property common to most dielectrics; it is difficult to contain because of its low surface tension. The coolant system pressure will vary from one atmosphere at rated power to approximately 20 psia at zero net power as result of maintaining constant cell temperature over the power range.

Stack waste heat is rejected to ambient through the air-cooled waste-heat heat exchanger. Coolant exit temperature is controlled by cycling the fan. The effect of cooling air flow on heat exchanger size was examined parametrically to determine the optimum air flow. It can be seen from Figure 49 that the optimum air flow is around 250 pph. Heat exchanger size increases dramatically below 250 pph and does not decrease appreciably above this flow. The cooling air fan provides 57 scfm at a pressure rise of 0.25 in. $H_2O$. The fan parasite power is estimated to be 10 watts.

The coolant accumulator is designed to accommodate a coolant volume change of 70 $in^3$ based on a temperature range of -65 to 350°F. The coolant circulating pump is designed to provide 960 pph of flow at a pressure rise of 5 psid. The pump parasite power is estimated to be 10 watts.

The start burner and heat exchanger are designed to heat up the stack from -25 to 300°F in 15 minutes. A start burner air flow of 180 pph was selected on the basis of the start heat exchanger trade study shown in Figure 50. The start air blower also provides 170 pph of air flow to the reformer burner during startup. The blower provides 80 scfm at a pressure rise of 1.2 in. $H_2O$. Blower power is estimated to be 55 watts. Start burner fuel flow is 6.3 pph.

The low-power electric heaters are identical to those in the premix system. They can provide up to 450 watts of heat in 150-watt increments for thermal control and voltage limiting at low powers. The thermal control system weights and volumes are summarized in Table 16.

TABLE 16. THERMAL CONTROL SYSTEM WEIGHT AND VOLUME SUMMARY

| Components | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Waste-Heat Heat Exchanger | 6.2 | 175 |
| Waste-Heat Heat Exchanger Fan | 0.5 | 105 |
| Start Heat Exchanger | 14.4 | 175 |
| Start Burner | 3.0 | 160 |
| Start Burner Fuel Valve | 3.0 | 100 |
| Start Air Blower | 3.5 | 105 |
| Coolant Pump | 2.5 | 105 |
| Coolant Accumulator | 2.0 | 90 |
| Coolant | 22.0 | --- |
| Total | 57.1 | 1015 |

2.3. Water Recovery. The function of the water recovery system is to supply liquid water to the reactant supply subsystem. The water recovery subsystem consists of the condenser and condenser cooling air fan.

The water recovery subsystem was designed to provide the fuel processor water flow required at rated power for an ambient temperature of 115°F. The condenser cooling air flow of 1500 pph was selected on the basis of the condenser optimization study shown in Figure 51. The condenser cooling air fan provides 338 scfm of air with a pressure rise of 0.1 in. $H_2O$. The fan parasite power is estimated to be 26 watts. The water recovery system weights and volumes are summarized in Table 17.

TABLE 17. WATER RECOVERY SUBSYSTEM WEIGHT AND VOLUME SUMMARY

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Condenser | 17 | 170 |
| Condenser Fan | 1 | 380 |
| Plumbing | 0.5 | 100 |
| Total | 18.5 | 650 |

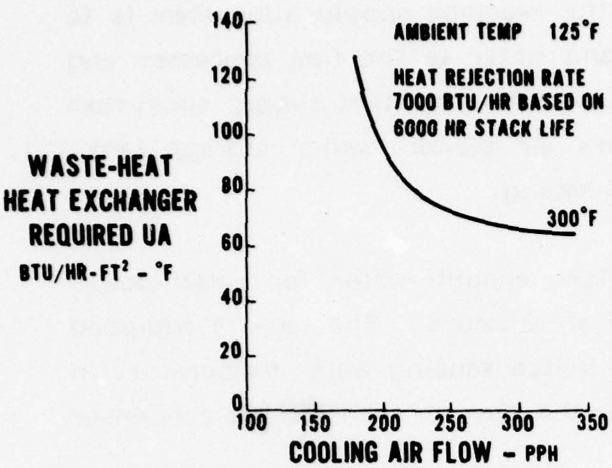


Figure 49.
Start Heat Exchanger Optimization

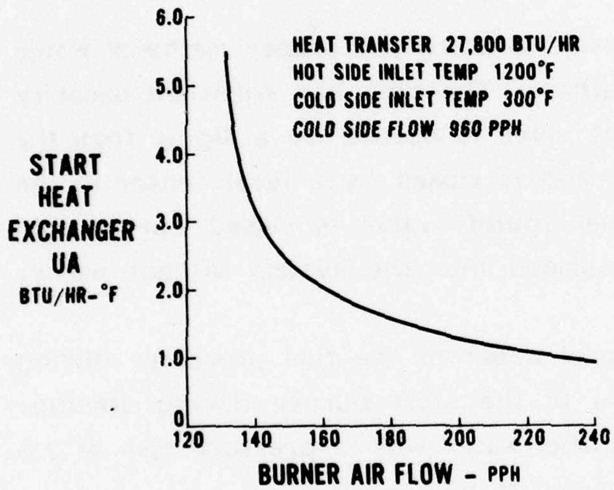


Figure 50.
Trade Study Waste Heat Exchanger Size versus Stack Exit Temperature and Cooling Air Flow

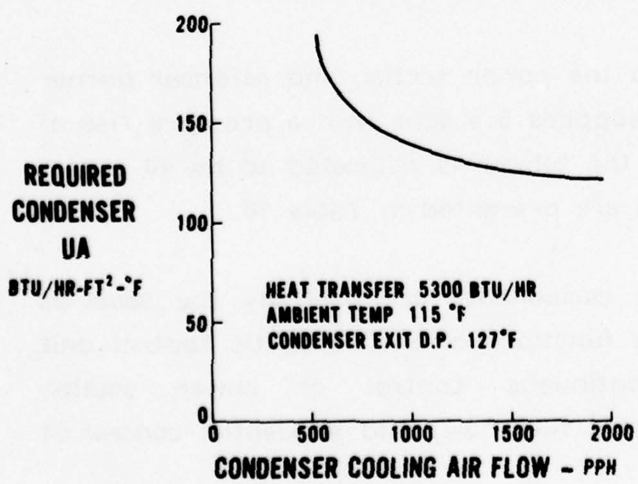


Figure 51. Condenser Optimization

2.4. Reactant Supply. The function of the reactant supply subsystem is to provide the correct mixture of methanol and water to the fuel processor and process air to the reformer burner and stack. The reactant supply subsystem consists of the process fuel pump, process air blower, water storage tank, methanol-water mixture tank valves, and plumbing.

The water storage tank is designed to store enough water for rated power operation on a 125°F, dry day for a period of 12 hours. The tank is equipped with a drain valve activated by a thermal switch sensing water temperature in the tank. A level sensor is also located in the tank to turn off the condenser fan to prevent overfilling.

The methanol-water mixture tank is used to store the proper methanol-water mixture for startup in subfreezing weather. The tank has sufficient capacity for three consecutive starts. The vent valve is opened by a signal from the level sensor in the water storage tank and is closed by a level sensor in the methanol-water mixture tank. The fuel shutoff valve is closed during cold weather to prevent fuel from being pumped into the system without water.

The process fuel pump supplies methanol-water to the fuel processor during startup and normal operation and fuel to the start burner during startup. The fuel pump supplies 11 pph of methanol-water with a pressure rise of 3.5 psid. The pump parasite power is estimated to be 5 watts.

The process air blower supplies air to the power section and reformer burner during normal operation. The blower supplies 5.6 scfm with a pressure rise of 2.1 in. $H_2O$. The parasite power of the blower is estimated to be 10 watts. The reactant supply weight and volume are presented in Table 18.

2.5. Control. The control subsystem components are basically the same as those in the premix fuel system. The functions of the automatic control unit differ, however, in providing continuous control of power section air flow, fuel processor air flow, process fuel flow, and sequential control of the following components:

| | |
|---|---|
| stack coolant inlet temperature | process air blower |
| low-power heater | process fuel pump |
| start air blower | start fuel vaporizers |
| reformer start fuel valve | main load contractor |
| power section start burner fuel valve | battery load switch |
| condenser exit temperature | fuel shutoff valve |
| coolant pump | reformer start air valve ignitors |

The control subsystem also monitors critical system parameters, stack coolant inlet temperature, reformer temperature, power section voltage, and power section current. The battery pack designed for two consecutive startup-shutdown cycles weighs 8 lb. Table 19 summarizes the energy required for startup and shutdown. The control subsystem weight and volume summary is presented in Table 20.

2.6 Fuel Processor and Power Conditioning. The fuel processor and power conditioning subsystems are identical to those in the premix fuel system.

3. POWER PLANT DESCRIPTION. As shown in Table 21, the characteristics of the power plant with water recovery are similar to those of the premixed fuel power plant except that weight and volume are increased by 91 lb and 1.7 $ft^3$ by the addition of the water recovery and freeze-protection equipment. The MTBF for this power plant is also lower by approximately 400 hours because of the additional components (see Figure 52). Water recovery may also adversely affect the operating life of the reformer. Catalyst suppliers and PSD experience indicate that sulfur and chloride contamination of the process water can cause low-temperature reforming catalyst degradation. Chloride and sulfur contamination of the water recovered from the power plant exhaust can occur due to leaching from plumbing and components. Should the Army decide to pursue design of a power plant with water recovery, an approach to water treatment or more frequent replacement of the catalyst will have to be considered. A weight and volume summary for the dc power plant with water recovery is presented in Table 22. A summary of parasite powers is shown in Table 23.

TABLE 18. REACTANT SUPPLY WEIGHT AND VOLUME SUMMARY

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| Process Fuel Pump and Plumbing | 3 | 75 |
| Process Air Blower and Ducting | 0.5 | 175 |
| Water Storage Tank | 1 | 345 |
| Methanol-Water Storage Tank | 1 | 345 |
| Water Tank Drain Valve | 2 | 13 |
| Methanol-Water Tank Vent Valve | 2 | 13 |
| Fuel Shutoff Valve | 3 | 20 |
| Total | 12.5 | 986 |

TABLE 19. STARTUP AND SHUTDOWN ENERGY REQUIREMENTS

| | | Energy, Watt-Hours | |
|---|---|---|---|
| Components | Power, Watts | Start | Shutdown |
| Start Blower | 55 | 14 | 0 |
| Coolant Pump | 10 | 2.5 | 2.5 |
| Fuel Processor Start Fuel Valve | 3 | 1 | 0 |
| Power Section Start Fuel Valve | 5 | 1 | 0 |
| Fuel Shutoff Valve | 10 | 2.5 | 2.5 |
| Fuel Processor Start Air Valve | 45 | 11.3 | 0 |
| Automatic Control Unit | 20 | 5 | 5 |
| Waste Heat Heat Exchanger | 10 | 2.5 | 2.5 |
| Water Drain Valve | 11 | 0 | 3 |
| Methanol-Water Vent Valve | 10 | 2.5 | 0 |
| Electric Fuel Vaporizers (2) | 3000 | 50 | 0 |
| Total | 3179 | 92.3 | 15.5 |

Energy required for two startup-shutdown cycles: 216 watt-hours

TABLE 20. CONTROL SYSTEM WEIGHT AND VOLUME SUMMARY

| Component | Weight, Lb | Volume, $In^3$ |
|---|---|---|
| ACU | 7 | 170 |
| Battery | 8 | 170 |
| Main Load Contactor | 1 | 30 |
| Exciters (2) | 1 | 60 |
| Instrument Panel | 5 | — |
| Total | 22 | 430 |

TABLE 21. WATER RECOVERY SYSTEM PRIMARY CHARACTERISTICS

| | | PD REQ'T. | DESIGN |
|---|---|---|---|
| RATED OUTPUT | KW | 1.5 | 1.5 |
| WEIGHT | LB | 150. | 259. |
| VOLUME | $FT^3$ | 6. | 8.1 |
| FUEL CONSUMPTION | LB/KW-HR | 2.2 | 1.22 |
| START TIME | MINUTES | 15. | 15. |
| OPERATING LIFE | HOURS | 6000. | 6000. |
| MTBF | HOURS | 750. | 1100. |
| TEMPERATURE RANGE | °F | -65 TO 125°F | -65 TO 125°F |
| NUMBER OF STARTS | | 2000. | 2000. |

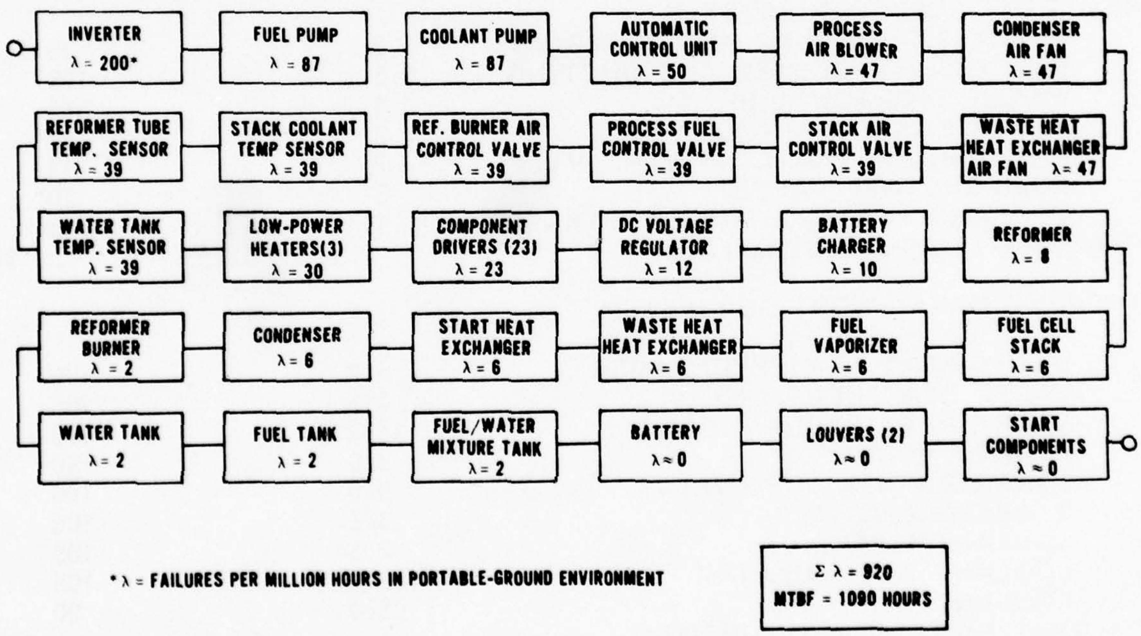


Figure 52. Reliability Model for Water Recovery 1.5-kW Methanol Power Plant

1. RADC-TR-75-22, January 1975, Nonelectronic Reliability Notebook.
2. MIL-HDBK-217B, 20 September 1974, Reliability Prediction of Electronic Equipment
3. AVCO Corp., March 1962, Reliability Physics.

TABLE 22. WATER RECOVERY SYSTEM WEIGHT AND VOLUME SUMMARY, DC SET

| | WEIGHT, LB | | VOLUME, $IN^3$ | |
|---|---|---|---|---|
| POWER SECTION | | | | |
| CELL STACK (WITHOUT COOLANT) | 64 | | 4990 | |
| CATHODE AIR VALVE | 3 | | 23 | |
| DUCTING | 1 | | 100 | |
| POWER SECTION SUBTOTAL | | 68 | | 5112 |
| CONTROL SUBSYSTEM | | | | |
| ACU | 7 | | 170 | |
| BATTERY | 8 | | 170 | |
| MAIN LOAD CONTACTOR | 1 | | 30 | |
| EXCITERS (2) | 1 | | 60 | |
| INSTRUMENT PANEL | 5 | | -- | |
| CONTROL SUBSYSTEM SUBTOTAL | | 22 | | 430 |
| REACTANT SUPPLY SUBSYSTEM | | | | |
| PROCESS FUEL PUMP AND PLUMBING | 3 | | 75 | |
| PROCESS AIR BLOWER AND DUCTING | 0.5 | | 175 | |
| WATER STORAGE TANK | 1 | | 345 | |
| WATER TANK DRAIN VALVE | 2 | | 13 | |
| METHANOL/WATER TANK VENT VALVE | 2 | | 13 | |
| FUEL SHUTOFF VALVE | 3 | | 20 | |
| METHANOL/WATER STORAGE TANK | 1 | | 345 | |
| REACTANT SUPPLY SUBTOTAL | | 12.5 | | 986 |
| THERMAL MANAGEMENT SUBSYSTEM | | | | |
| WASTE HEAT HEAT EXCHANGER | 6.2 | | 175 | |
| WASTE HEAT HEAT FAN | 0.5 | | 105 | |
| START HEAT EXCHANGER | 14.4 | | 175 | |
| START BURNER | 3.0 | | 160 | |
| START BURNER FUEL VALVE | 3.0 | | 100 | |
| START AIR BLOWER | 3.5 | | 105 | |
| COOLANT PUMP | 2.5 | | 105 | |
| COOLANT ACCUMULATOR | 2.0 | | 105 | |
| COOLANT | 22.0 | | 90 | |
| THERMAL MANAGEMENT SUBTOTAL | | 57.1 | | 1015 |

TABLE 22. (Continued)

| | WEIGHT, LB | | VOLUME, $IN^3$ | |
|---|---|---|---|---|
| WATER RECOVERY SUBSYSTEM | | | | |
| CONDENSER | 17 | | 170 | |
| CONDENSER FAN | 1 | | 380 | |
| PLUMBING | 0.5 | | 100 | |
| WATER RECOVERY SUBTOTAL | | 18.5 | | 650 |
| FUEL PROCESSING SUBSYSTEM | | | | |
| BURNER/VAPORIZER/REFORMER | 30 | | 2074 | |
| DUCTING AND VALVES | 13 | | 660 | |
| FUEL PROCESSOR SUBSYSTEM SUBTOTAL | | 43.0 | | 2730 |
| POWER CONDITIONING | | | | |
| DC VOLTAGE REGULATOR | 14 | | 660 | |
| POWER CONDITIONING SUBTOTAL | | 14.0 | | |
| STRUCTURE | 23.5 | | | |
| STRUCTURE SUBTOTAL | | 23.5 | | |
| TOTAL | | 258.6 | 11583 | |

TABLE 23. WATER RECOVERY PARASITE POWER SUMMARY

| COMPONENT | POWER, WATTS |
|---|---|
| FUEL PUMP | 5 |
| PROCESS AIR BLOWER | 10 |
| CONDENSER FAN | 26 |
| WASTE HEAT HEAT EXCHANGER FAN | 10 |
| COOLANT PUMP | 10 |
| BURNER AIR VALVE | 20 |
| STACK AIR VALVE | 20 |
| ACU | 20 |
| BATTERY CHARGER | 30 |
| MAIN LOAD CONTACTOR | 10 |
| PROCESS FUEL VALVE | 3 |
| TOTAL | 164 |

## CONCLUSIONS

The following conclusions have been drawn from the results of the data base review and data base confirmation parts of the program:

1. A baseline activity can be defined for steam reforming reagent-grade methanol on catalyst T2130 (United Catalysts, Inc.) at rated conditions: (pressure, 1 atmosphere; $H_2O/CH_3OH$ mole ratio, 1.5:1; temperature, 400 to 550°F).

2. Operation at off-rated conditions per temperature (<600°F), pressure (50 psia), and $H_2O/CH_3OH$ mole ratio (<0.7) does not affect this baseline activity.

3. The effect of impurities in the methanol feed (ethanol, isobutanol, sulfur, and chlorine) on baseline activity can be estimated by deactivation factors that permit estimation of end-of-life activity for the catalyst.

4. Ethanol and isobutanol deactivate by reversible adsorption on the catalyst surface. A minimum activity is reached that has the same value for both impurities at saturation adsorption coverage ($\sim\frac{1}{4}$ baseline activity). This minimum is reached at 400 ppmw ethanol and 100 ppmw isobutanol.

5. This deactivation may be compensated for by an approximately 50°F increase in mean operating temperature.

6. An experiment with technical-grade methanol containing approximately 100 ppmw ethanol confirmed that after an initial deactivation, a constant, lower activity value was established.

7. Using deactivation factors, tradeoffs may be evaluated between fuel purity, availability, and power plant performance.

The conclusions drawn from the results of the conceptual design study are:

1. The premix fuel power plant utilizing an air-cooled stack with recycle has the greatest potential for meeting the purchase description requirements. Weight and volume, although exceeding the purchase description requirement by 17%, can be reduced to meet the Army's goal by increasing fuel consumption. The new level of fuel consumption will remain lower than goal requirements.

2. Adding water recovery capability increases power plant weight by 48% and volume by 16%; it also adds complexity for freeze protection and to development cost. Water recovery may reduce reformer life or require water treatment.

3. The 2000 starts and low ambient temperature requirements are not typical of commercial applications and require further investigation.

4. Short-term operation on unreacted methanol (concentrations up to 20%) and on ethanol (up to 6% concentration) is not detrimental to fuel cell performance at 375°F.

5. A high-performance reformer design has been defined that meets all power plant process requirements.

6. The reformer should operate satisfactorily on methanol containing up to 100 ppm higher alcohols, which includes approximately 40% of the commercial methanol sources.

# RECOMMENDATIONS

The following recommendations are made by PSD as the result of the reported program:

1. To compensate for deactivation due to impurities, the reformer may run at temperatures greater than 500°F. The behavior of higher alcohol impurities in this temperature range should be investigated, in particular to determine if carbon laydown may occur.

2. No quantitative analysis for effluent ethanol and isobutanol was possible in this program. The conversion and product distribution from ethanol and isobutanol should be determined at reformer operating conditions.

3. The effect of other possible reformer products, e.g., ethers and aldehydes, on fuel cell performance should be evaluated.

4. Steam reforming of methanol with high impurity levels of ethanol (>500 ppmw) and isobutanol (>2500 ppmw) should be investigated to simulate operation on methyl fuels.

5. Several, less pure, grades of methanol should be run at high space velocity to check for effects of impurities, other than higher alcohols, which may be detrimental to catalyst activity.

6. The effect of total pressure and of reactant partial pressures on reaction rate should be determined.

7. Alternative catalyst systems that may steam-reform higher alcohols at intermediate temperatures (lower than conventional reforming) should be sought.

8. The effects of a large number of starts and low ambient temperature should be investigated.

9. Investigate tradeoffs between longer or shorter start time (30 minutes) and/or added weight versus startup/shutdown losses should be considered.

10. Effects of methanol and higher alcohols on long-term fuel cell performance at lower temperatures (325 to 350°F) should be investigated.

11. The transient characteristics of the system, particularly the fuel processing subsystem, should be investigated.

12. The fuel consumption versus weight tradeoffs should be pursued.

## GLOSSARY

DEACTIVATION FACTOR, $\eta$: an adjustment factor, applied to a baseline catalyst activity, to estimate the lower activity to be expected in the presence of catalyst poisons or other causes of decreasing activity

FUEL: moles $CH_3OH$/hr
MA: moles argon/hr
$MCH_4$: moles $CH_4$/hr
MCO: moles CO/hr
$MCO_2$: moles $CO_2$/hr
$MH_2$: moles $H_2$/hr
$MH_2O$: moles $H_2O$/hr
$MN_2$: moles $N_2$/hr
$MO_2$: moles $O_2$/hr
Mode III: 1.5-kW, 60-Hz, Model MEPX031A
Mode IV: 1.5-kW, 28-volt direct current, Model MEPX030A
PPH: pounds per hours mass
PPMW: parts per million, weight
PSID: pounds force per square inch, differential
PT: total pressure (pounds force per square inch, absolute)
RM-1: Simulated reformed methane, i.e., 70% $H_2$, 1% CO, 19% $CO_2$
THSV: theoretical hydrogen space velocity; the reactor space velocity, in volumes of gas per volume reactor per hour, based on the hydrogen produced from the methanol feed in reaction:

$$CH_3OH + H_2O \rightarrow CO_2 + 3H_2$$

1 TF: temperature in degrees Fahrenheit
UTILIZATION (U): cell reactant consumption/inlet reactant flow

# APPENDIX A

## Operating Parameters for 1.5-kW Army Methanol Power Plant with Premix Fuel

# TABLE A-1

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 1 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .35969 | 1.3371 | .16794E-01 | .0 | 49.6025 |
| 2 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .35969 | 1.3371 | .16794E-01 | .0 | 49.6025 |
| 3 | 296.56 | 14.696 | .0 | .62927 | .0 | .0 | .0 | 1.8299 | 7.9717 | .10012 | .0 | 297.227 |
| 4 | 296.56 | 14.696 | .0 | .62927 | .0 | .0 | .0 | 1.8299 | 7.9717 | .10012 | .0 | 297.227 |
| 12 | 298.56 | 14.696 | .0 | .22470E-01 | .0 | .0 | .0 | .65341E-01 | .28465 | .35750E-02 | .0 | 10.6134 |
| 13 | 298.56 | 14.696 | .0 | .22470E-01 | .0 | .0 | .0 | .65341E-01 | .28465 | .35750E-02 | .0 | 10.6134 |
| | 322.11 | 14.697 | .64141E-01 | .58418E-01 | .0 | .41918E-02 | .59320E-01 | .65341E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| 14 | 1964.2 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 1964.2 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| 15 | 1207.3 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 1207.3 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| 16 | 811.82 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 811.82 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 811.82 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 811.82 | 14.697 | .0 | .12256 | .0 | .0 | .63512E-01 | .31175E-01 | .28465 | .35750E-02 | .0 | 14.1184 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 101 | *********** | 14.700 | .0 | .95267E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .63512E-01 | 3.75138 |
| 103 | *********** | 14.700 | .0 | .95267E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .63512E-01 | 3.75138 |
| 104 | 350.31 | 14.700 | .0 | .95267E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .63512E-01 | 3.75138 |
| | 350.32 | 14.700 | .0 | .95267E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .63512E-01 | 3.75138 |
| 105 | 399.41 | 14.700 | .18634 | .35948E-01 | .0 | .41918E-02 | .59320E-01 | .0 | .0 | .0 | .0 | 3.75138 |
| 106 | 399.41 | 14.700 | .18634 | .35948E-01 | .0 | .41918E-02 | .59320E-01 | .0 | .0 | .0 | .0 | 3.75138 |
| 107 | 367.56 | 14.700 | .64141E-01 | .35948E-01 | .0 | .41918E-02 | .59320E-01 | .0 | .0 | .0 | .0 | 3.50501 |
| 108 | 367.57 | 14.700 | .64141E-01 | .35948E-01 | .0 | .41918E-02 | .59320E-01 | .0 | .0 | .0 | .0 | 3.50502 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 21 | 367.56 | 14.696 | .0 | .62927 | .0 | .0 | .0 | 1.4702 | 6.6346 | .83325E-01 | .0 | 247.585 |
| | 367.56 | 14.696 | .0 | .62927 | .0 | .0 | .0 | 1.4702 | 6.6346 | .83325E-01 | .0 | 247.585 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 5 | 298.56 | 14.696 | .0 | .60680 | .0 | .0 | .0 | 1.7645 | 7.6871 | .96543E-01 | .0 | 286.614 |
| 7 | 298.56 | 14.696 | .0 | .60680 | .0 | .0 | .0 | 1.7645 | 7.6871 | .96543E-01 | .0 | 286.614 |
| 8 | 367.56 | 14.696 | .0 | .72900 | .0 | .0 | .0 | 1.7034 | 7.6871 | .96543E-01 | .0 | 286.860 |
| 9 | 367.56 | 14.696 | .0 | .72900 | .0 | .0 | .0 | 1.7034 | 7.6871 | .96543E-01 | .0 | 286.860 |
| 10 | 367.56 | 14.696 | .0 | .10001 | .0 | .0 | .0 | .23368 | 1.0545 | .13244E-01 | .0 | 39.3520 |
| 11 | 367.56 | 14.696 | .0 | .10001 | .0 | .0 | .0 | .23368 | 1.0545 | .13244E-01 | .0 | 39.3520 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 20 | 367.56 | 14.696 | .0 | .62899 | .0 | .0 | .0 | 1.4697 | 6.6325 | .83299E-01 | .0 | 247.508 |
| | 367.56 | 14.696 | .0 | .62899 | .0 | .0 | .0 | 1.4697 | 6.6325 | .83299E-01 | .0 | 247.508 |

NET AC POWER = 1500.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = -65.0 °F    RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 37.1 AMPS

DC VOLTAGE 54.0 VOLTS

SPECIFIC FUEL CONSUMPTION 0.29352 LB/KW-HR

BOL CELL PERFORMANCE

# TABLE A-2

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .28460 | 1.0580 | .13287E-01 | .0 | 39.2781 |
| 2 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .28460 | 1.0580 | .13287E-01 | .0 | 39.2781 |
| 3 | 309.30 | 14.696 | .0 | .68669 | .0 | .0 | .0 | 1.7705 | 7.8573 | .98681E-01 | .0 | 293.099 |
| 4 | 309.30 | 14.696 | .0 | .68669 | .0 | .0 | .0 | 1.7705 | 7.8573 | .98681E-01 | .0 | 293.099 |
| 12 | 309.30 | 14.696 | .0 | .27932E-01 | .0 | .0 | .0 | .72018E-01 | .31960 | .40139E-02 | .0 | 11.9221 |
| 13 | 309.30 | 14.696 | .0 | .27932E-01 | .0 | .0 | .0 | .72018E-01 | .31960 | .40139E-02 | .0 | 11.9221 |
| | 324.42 | 14.697 | .53178E-01 | .57915E-01 | .0 | .34963E-02 | .49478E-01 | .72018E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| 14 | 1670.9 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 1670.9 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| 15 | 1041.3 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 1041.3 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| 16 | 720.04 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 720.04 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 720.04 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 720.04 | 14.697 | .0 | .11109 | .0 | .0 | .52975E-01 | .43681E-01 | .31960 | .40139E-02 | .0 | 14.8449 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | ********** | 14.700 | .0 | .79462E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52975E-01 | 3.12901 |
| 103 | ********** | 14.700 | .0 | .79462E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52975E-01 | 3.12901 |
| 104 | 350.31 | 14.700 | .0 | .79462E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52975E-01 | 3.12901 |
| | 350.32 | 14.700 | .0 | .79462E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52975E-01 | 3.12901 |
| 105 | 387.68 | 14.700 | .15543 | .29984E-01 | .0 | .34963E-02 | .49478E-01 | .0 | .0 | .0 | .0 | 3.12900 |
| 106 | 387.68 | 14.700 | .15543 | .29984E-01 | .0 | .34963E-02 | .49478E-01 | .0 | .0 | .0 | .0 | 3.12900 |
| 107 | 363.99 | 14.700 | .53178E-01 | .29984E-01 | .0 | .34963E-02 | .49478E-01 | .0 | .0 | .0 | .0 | 2.92287 |
| 108 | 363.99 | 14.700 | .53178E-01 | .29984E-01 | .0 | .34963E-02 | .49478E-01 | .0 | .0 | .0 | .0 | 2.92287 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 363.98 | 14.696 | .0 | .68669 | .0 | .0 | .0 | 1.4859 | 6.7993 | .85394E-01 | .0 | 253.821 |
| | 363.98 | 14.696 | .0 | .68669 | .0 | .0 | .0 | 1.4859 | 6.7993 | .85394E-01 | .0 | 253.821 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 309.30 | 14.696 | .0 | .65876 | .0 | .0 | .0 | 1.6985 | 7.5377 | .94667E-01 | .0 | 281.177 |
| 7 | 309.30 | 14.696 | .0 | .65876 | .0 | .0 | .0 | 1.6985 | 7.5377 | .94667E-01 | .0 | 281.177 |
| 8 | 363.99 | 14.696 | .0 | .76101 | .0 | .0 | .0 | 1.6474 | 7.5377 | .94667E-01 | .0 | 281.383 |
| 9 | 363.98 | 14.696 | .0 | .76101 | .0 | .0 | .0 | 1.6474 | 7.5377 | .94667E-01 | .0 | 281.383 |
| 10 | 363.98 | 14.696 | .0 | .74752E-01 | .0 | .0 | .0 | .16182 | .74040 | .92989E-02 | .0 | 27.6395 |
| 11 | 363.98 | 14.696 | .0 | .74752E-01 | .0 | .0 | .0 | .16182 | .74040 | .92989E-02 | .0 | 27.6395 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 363.98 | 14.696 | .0 | .68626 | .0 | .0 | .0 | 1.4856 | 6.7975 | .85368E-01 | .0 | 253.744 |
| | 363.98 | 14.696 | .0 | .68626 | .0 | .0 | .0 | 1.4856 | 6.7975 | .85368E-01 | .0 | 253.743 |

NET AC POWER = 1250.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AMB}$ = -65.0 °F    RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 31.1 AMPS

DC VOLTAGE 54.97 VOLTS

SPECIFIC FUEL CONSUMPTION 1.36 LBS/KW-HR

BOL CELL PERFORMANCE

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# TABLE A-3

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .21267 | .79061 | .99295E-02 | .0 | 29.3518 |
| 2 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .21267 | .79061 | .99295E-02 | .0 | 29.3518 |
| 3 | 319.67 | 14.696 | .0 | .76829 | .0 | .0 | .0 | 1.7007 | 7.7485 | .97315E-01 | .0 | 289.233 |
| 4 | 319.67 | 14.696 | .0 | .76829 | .0 | .0 | .0 | 1.7007 | 7.7485 | .97315E-01 | .0 | 289.233 |
| 12 | 319.67 | 14.696 | .0 | .35537E-01 | .0 | .0 | .0 | .78665E-01 | .35841 | .45013E-02 | .0 | 13.3784 |
| 13 | 319.67 | 14.696 | .0 | .35537E-01 | .0 | .0 | .0 | .78665E-01 | .35841 | .45013E-02 | .0 | 13.3784 |
| | 328.44 | 14.697 | .42705E-01 | .59764E-01 | .0 | .28250E-02 | .39979E-01 | .78665E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| 14 | 1365.4 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 1365.4 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| 15 | 683.52 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 683.52 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| 16 | 633.88 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 633.88 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 633.88 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 633.88 | 14.697 | .0 | .10247 | .0 | .0 | .42804E-01 | .55900E-01 | .35841 | .45013E-02 | .0 | 15.7396 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | ********** | 14.700 | .0 | .64206E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42804E-01 | 2.52824 |
| 103 | ********** | 14.700 | .0 | .64206E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42804E-01 | 2.52824 |
| 104 | 350.31 | 14.700 | .0 | .64206E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42804E-01 | 2.52824 |
| | 350.32 | 14.700 | .0 | .64206E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42804E-01 | 2.52824 |
| 105 | 376.60 | 14.700 | .12559 | .24227E-01 | .0 | .28250E-02 | .39979E-01 | .0 | .0 | .0 | .0 | 2.52824 |
| 106 | 376.60 | 14.700 | .12559 | .24227E-01 | .0 | .28250E-02 | .39979E-01 | .0 | .0 | .0 | .0 | 2.52824 |
| 107 | 360.53 | 14.700 | .42705E-01 | .24227E-01 | .0 | .28250E-02 | .39979E-01 | .0 | .0 | .0 | .0 | 2.36115 |
| 108 | 360.53 | 14.700 | .42705E-01 | .24227E-01 | .0 | .28250E-02 | .39979E-01 | .0 | .0 | .0 | .0 | 2.36115 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 360.52 | 14.696 | .0 | .76829 | .0 | .0 | .0 | 1.4880 | 6.9579 | .87386E-01 | .0 | 259.882 |
| | 360.52 | 14.696 | .0 | .76829 | .0 | .0 | .0 | 1.4880 | 6.9579 | .87386E-01 | .0 | 259.882 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 319.67 | 14.696 | .0 | .73275 | .0 | .0 | .0 | 1.6220 | 7.3901 | .92814E-01 | .0 | 275.855 |
| 7 | 319.67 | 14.696 | .0 | .73275 | .0 | .0 | .0 | 1.6220 | 7.3901 | .92814E-01 | .0 | 275.855 |
| 8 | 360.53 | 14.696 | .0 | .81563 | .0 | .0 | .0 | 1.5806 | 7.3901 | .92814E-01 | .0 | 276.022 |
| 9 | 360.52 | 14.696 | .0 | .81563 | .0 | .0 | .0 | 1.5806 | 7.3901 | .92814E-01 | .0 | 276.022 |
| 10 | 360.52 | 14.696 | .0 | .47756E-01 | .0 | .0 | .0 | .92546E-01 | .43270 | .58344E-02 | .0 | 16.1614 |
| 11 | 360.52 | 14.696 | .0 | .47756E-01 | .0 | .0 | .0 | .92546E-01 | .43270 | .58344E-02 | .0 | 16.1614 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 360.52 | 14.696 | .0 | .76787 | .0 | .0 | .0 | 1.4880 | 6.9574 | .87380E-01 | .0 | 259.861 |
| | 360.52 | 14.696 | .0 | .76787 | .0 | .0 | .0 | 1.4880 | 6.9574 | .87380E-01 | .0 | 259.861 |

NET AC POWER = 1000.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

TAMB = -65.0 °F  RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 25.19 AMPS

DC VOLTAGE 56.01 VOLTS

SPECIFIC FUEL CONSUMPTION 1.37 LBS/KW-HR

BOL CELL PERFORMANCE

TABLE A-4

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14,696 | .0 | .0 | .0 | .0 | .0 | .14379 | .53454 | .67135E-02 | .0 | 19,8452 |
| 2 | ********** | 14,696 | .0 | .0 | .0 | .0 | .0 | .14379 | .53454 | .67135E-02 | .0 | 19,8452 |
| 3 | 329,68 | 14,696 | .0 | .91077 | .0 | .0 | .0 | 1,6017 | 7,6425 | .95985E-01 | .0 | 285,609 |
| 4 | 329,68 | 14,696 | .0 | .91077 | .0 | .0 | .0 | 1,6017 | 7,6425 | .95985E-01 | .0 | 285,609 |
| 12 | 329,68 | 14,696 | .0 | .48294E-01 | .0 | .0 | .0 | .84931E-01 | .40525 | .50897E-02 | .0 | 15,1446 |
| 13 | 329,68 | 14,696 | .0 | .48294E-01 | .0 | .0 | .0 | .84931E-01 | .40525 | .50897E-02 | .0 | 15,1447 |
| | 333,95 | 14,697 | .32682E-01 | .66960E-01 | .0 | .21766E-02 | .30803E-01 | .84931E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| 14 | 1107,6 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 1107,6 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| 15 | 734,06 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 734,06 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| 16 | 553,21 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 553,21 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 553,21 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 553,21 | 14,697 | .0 | .99642E-01 | .0 | .0 | .32979E-01 | .67502E-01 | .40525 | .50897E-02 | .0 | 16,9634 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | ********** | 14,700 | .0 | .49469E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32979E-01 | 1,94795 |
| 103 | ********** | 14,700 | .0 | .49469E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32979E-01 | 1,94795 |
| 104 | 350,31 | 14,700 | .0 | .49469E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32979E-01 | 1,94795 |
| | 350,32 | 14,700 | .0 | .49469E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32979E-01 | 1,94795 |
| 105 | 366,14 | 14,700 | .96761E-01 | .18666E-01 | .0 | .21766E-02 | .30803E-01 | .0 | .0 | .0 | .0 | 1,94794 |
| 106 | 366,14 | 14,700 | .96761E-01 | .18666E-01 | .0 | .21766E-02 | .30803E-01 | .0 | .0 | .0 | .0 | 1,94794 |
| 107 | 357,19 | 14,700 | .32682E-01 | .18666E-01 | .0 | .21766E-02 | .30803E-01 | .0 | .0 | .0 | .0 | 1,81876 |
| 108 | 357,19 | 14,700 | .32682E-01 | .18666E-01 | .0 | .21766E-02 | .30803E-01 | .0 | .0 | .0 | .0 | 1,81876 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 357,18 | 14,696 | .0 | .91077 | .0 | .0 | .0 | 1.4579 | 7,1080 | .89271E-01 | .0 | 265,764 |
| | 357,18 | 14,696 | .0 | .91077 | .0 | .0 | .0 | 1.4579 | 7,1080 | .89271E-01 | .0 | 265,764 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 329,68 | 14,696 | .0 | .86248 | .0 | .0 | .0 | 1.5168 | 7,2373 | .90895E-01 | .0 | 270,464 |
| 7 | 329,68 | 14,696 | .0 | .86248 | .0 | .0 | .0 | 1.5168 | 7,2373 | .90895E-01 | .0 | 270,464 |
| 8 | 357,19 | 14,696 | .0 | .92656 | .0 | .0 | .0 | 1.4847 | 7,2373 | .90895E-01 | .0 | 270,594 |
| 9 | 357,18 | 14,696 | .0 | .92656 | .0 | .0 | .0 | 1.4847 | 7,2373 | .90895E-01 | .0 | 270,594 |
| 10 | 357,18 | 14,696 | .0 | .16431E-01 | .0 | .0 | .0 | .26330E-01 | .12834 | .16119E-02 | .0 | 4,79864 |
| 11 | 357,18 | 14,696 | .0 | .16431E-01 | .0 | .0 | .0 | .26330E-01 | .12834 | .16119E-02 | .0 | 4,79864 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 357,18 | 14,696 | .0 | .91012 | .0 | .0 | .0 | 1.4584 | 7,1089 | .89283E-01 | .0 | 265,795 |
| | 357,18 | 14,696 | .0 | .91012 | .0 | .0 | .0 | 1.4584 | 7,1089 | .89283E-01 | .0 | 265,795 |

NET AC POWER = 750.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AMB}$ = -65.0 °F  RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 19.47 AMPS

DC VOLTAGE 57.16 VOLTS

SPECIFIC FUEL CONSUMPTION 1.41 LBS/KW-HR

BOL CELL PERFORMANCE

# TABLE A-5

## 15-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ........... | 14.696 | .0 | .0 | .0 | .0 | .0 | .20466 | .77500 | .97420E-02 | .0 | 28.7977 |
| 2 | ........... | 14.696 | .0 | .0 | .0 | .0 | .0 | .20466 | .77500 | .97420E-02 | .0 | 28.7977 |
| 3 | 315.44 | 14.696 | .0 | .67984 | .0 | .0 | .0 | 1.7448 | 7.7650 | .97522E-01 | .0 | 289.649 |
| 4 | 316.44 | 14.696 | .0 | .67984 | .0 | .0 | .0 | 1.7448 | 7.7650 | .97522E-01 | .0 | 289.649 |
| 12 | 315.44 | 14.696 | .0 | .33981E-01 | .0 | .0 | .0 | .87411E-01 | .38812 | .48744E-02 | .0 | 14.4775 |
| 13 | 316.45 | 14.696 | .0 | .33981E-01 | .0 | .0 | .0 | .87411E-01 | .38812 | .48744E-02 | .0 | 14.4775 |
| | 563.56 | 14.697 | .37088E-01 | .54961E-01 | .0 | .24465E-02 | .34622E-01 | .87411E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| 14 | 1223.5 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| | 1223.5 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| 15 | 795.61 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| | 795.61 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| 16 | 585.41 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| | 585.41 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| | 580.41 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48744E-02 | .0 | 16.5225 |
| | 585.41 | 14.697 | .0 | .92049E-01 | .0 | .0 | .37069E-01 | .67644E-01 | .38812 | .48704E-02 | .0 | 16.5225 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | ........... | 14.700 | .0 | .55603E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .37069E-01 | 2.18950 |
| 103 | ........... | 14.700 | .0 | .55603E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .37069E-01 | 2.18950 |
| 104 | 550.31 | 14.700 | .0 | .55603E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .37069E-01 | 2.18950 |
| | 550.32 | 14.700 | .0 | .55603E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .37069E-01 | 2.18950 |
| 105 | 570.33 | 14.700 | .10876 | .20981E-01 | .0 | .24465E-02 | .34622E-01 | .0 | .0 | .0 | .0 | 2.18950 |
| 106 | 570.33 | 14.700 | .10876 | .20981E-01 | .0 | .24465E-02 | .34622E-01 | .0 | .0 | .0 | .0 | 2.18950 |
| 107 | 556.48 | 14.700 | .37088E-01 | .20981E-01 | .0 | .24465E-02 | .34622E-01 | .0 | .0 | .0 | .0 | 2.04501 |
| 108 | 554.48 | 14.700 | .37088E-01 | .20981E-01 | .0 | .24465E-02 | .34622E-01 | .0 | .0 | .0 | .0 | 2.04501 |

| 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 556.48 | 14.696 | .0 | .67984 | .0 | .0 | .0 | 1.5402 | 6.9893 | .87780E-01 | .0 | 260.851 |
| | 555.48 | 14.696 | .0 | .67984 | .0 | .0 | .0 | 1.5402 | 6.9893 | .87780E-01 | .0 | 260.851 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 316.44 | 14.696 | .0 | .64586 | .0 | .0 | .0 | 1.0614 | 7.3769 | .92647E-01 | .0 | 275.171 |
| 7 | 325.80 | 14.696 | .0 | .64586 | .0 | .0 | .0 | 1.0614 | 7.3769 | .92647E-01 | .0 | 275.171 |
| 8 | 555.48 | 14.696 | .0 | .71753 | .0 | .0 | .0 | 1.0256 | 7.3769 | .92647E-01 | .0 | 275.315 |
| 9 | 555.48 | 14.696 | .0 | .71753 | .0 | .0 | .0 | 1.0256 | 7.3769 | .92647E-01 | .0 | 275.316 |
| 10 | 556.48 | 14.696 | .0 | .37702E-01 | .0 | .0 | .0 | .85413E-01 | .38761 | .46680E-02 | .0 | 14.4661 |
| 11 | 555.48 | 14.696 | .0 | .37702E-01 | .0 | .0 | .0 | .85413E-01 | .38761 | .48680E-02 | .0 | 14.4661 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 556.48 | 14.696 | .0 | .67985 | .0 | .0 | .0 | 1.5402 | 6.9893 | .87779E-01 | .0 | 260.850 |
| | 555.45 | 14.696 | .0 | .67985 | .0 | .0 | .0 | 1.5402 | 6.9893 | .87779E-01 | .0 | 260.850 |

NET AC POWER = 705.0 WATTS

HEATER POWER = 160.0 WATTS

INVERTER EFFICIENCY = 84.0 %

TAVG = -65.0 °F RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 21.78 AMPS

DC VOLTAGE 56.87 VOLTS

SPECIFIC FUEL CONSUMPTION 1.68 LBS/KW-HR

BOL CELL PERFORMANCE

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TABLE A-6

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 1 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .17992 | .66884 | .84002E-02 | .0 | 24.8311 |
| 2 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .17992 | .66884 | .84002E-02 | .0 | 24.8311 |
| 3 | 322.57 | 14.696 | .0 | .71053 | .0 | .0 | .0 | 1.7219 | 7.7221 | .96982E-01 | .0 | 288.118 |
| 4 | 322.57 | 14.696 | .0 | .71053 | .0 | .0 | .0 | 1.7219 | 7.7221 | .96982E-01 | .0 | 288.118 |
| 12 | 322.57 | 14.696 | .0 | .37784E-01 | .0 | .0 | .0 | .91569E-01 | .41064 | .51572E-02 | .0 | 15.3213 |
| 13 | 322.57 | 14.696 | .0 | .37784E-01 | .0 | .0 | .0 | .91569E-01 | .41064 | .51572E-02 | .0 | 15.3214 |
| | 327.94 | 14.696 | .32930E-01 | .56443E-01 | .0 | .21758E-02 | .30791E-01 | .91569E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| 14 | 1107.3 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 1107.3 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| 15 | 733.82 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 733.82 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| 16 | 553.07 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 553.07 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 553.07 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 553.07 | 14.696 | .0 | .89373E-01 | .0 | .0 | .32966E-01 | .74016E-01 | .41064 | .51572E-02 | .0 | 17.1399 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | *********** | 14.700 | .0 | .49450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32966E-01 | 1.94719 |
| 103 | *********** | 14.700 | .0 | .49450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32966E-01 | 1.94719 |
| 104 | 350.31 | 14.700 | .0 | .49450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32966E-01 | 1.94719 |
| | 350.32 | 14.700 | .0 | .49450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32966E-01 | 1.94719 |
| 105 | 365.99 | 14.700 | .96723E-01 | .18659E-01 | .0 | .21758E-02 | .30791E-01 | .0 | .0 | .0 | .0 | 1.94719 |
| 106 | 365.99 | 14.700 | .96723E-01 | .18659E-01 | .0 | .21758E-02 | .30791E-01 | .0 | .0 | .0 | .0 | 1.94719 |
| 107 | 357.09 | 14.700 | .32930E-01 | .18659E-01 | .0 | .21758E-02 | .30791E-01 | .0 | .0 | .0 | .0 | 1.81858 |
| 108 | 357.09 | 14.700 | .32930E-01 | .18659E-01 | .0 | .21758E-02 | .30791E-01 | .0 | .0 | .0 | .0 | 1.81858 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 357.09 | 14.696 | .0 | .71053 | .0 | .0 | .0 | 1.5420 | 7.0532 | .88582E-01 | .0 | 263.287 |
| | 357.09 | 14.696 | .0 | .71053 | .0 | .0 | .0 | 1.5420 | 7.0532 | .88582E-01 | .0 | 263.287 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 322.57 | 14.696 | .0 | .67275 | .0 | .0 | .0 | 1.6304 | 7.3114 | .91824E-01 | .0 | 272.796 |
| 7 | 329.98 | 14.696 | .0 | .67275 | .0 | .0 | .0 | 1.6304 | 7.3114 | .91824E-01 | .0 | 272.796 |
| 8 | 357.09 | 14.696 | .0 | .73654 | .0 | .0 | .0 | 1.5985 | 7.3114 | .91824E-01 | .0 | 272.925 |
| 9 | 357.09 | 14.696 | .0 | .73654 | .0 | .0 | .0 | 1.5985 | 7.3114 | .91824E-01 | .0 | 272.925 |
| 10 | 357.09 | 14.696 | .0 | .26058E-01 | .0 | .0 | .0 | .56553E-01 | .25867 | .32487E-02 | .0 | 9.65598 |
| 11 | 357.09 | 14.696 | .0 | .26058E-01 | .0 | .0 | .0 | .56553E-01 | .25867 | .32487E-02 | .0 | 9.65598 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 357.09 | 14.696 | .0 | .71048 | .0 | .0 | .0 | 1.5419 | 7.0527 | .88576E-01 | .0 | 263.269 |
| | 357.08 | 14.696 | .0 | .71048 | .0 | .0 | .0 | 1.5419 | 7.0527 | .88576E-01 | .0 | 263.269 |

NET AC POWER = 600.0 WATTS

HEATER POWER = 150.0 WATTS

INVERTER EFFICIENCY = 84.0 %

TAVG = -65.0 °F RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 19.39 AMPS

DC VOLTAGE 57.41 VOLTS

SPECIFIC FUEL CONSUMPTION 1.76 LBS/KW-HR

BOL CELL PERFORMANCE

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# TABLE A-7

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .21770 | .80929 | .10164E-01 | .0 | 30.0454 |
| 2 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .21770 | .80929 | .10164E-01 | .0 | 30.0454 |
| 3 | 315.33 | 14.696 | .0 | .58178 | .0 | .0 | .0 | 1.8077 | 7.8016 | .97982E-01 | .0 | 290.810 |
| 4 | 315.33 | 14.696 | .0 | .58178 | .0 | .0 | .0 | 1.8077 | 7.8016 | .97982E-01 | .0 | 290.810 |
| 12 | 315.33 | 14.696 | .0 | .30819E-01 | .0 | .0 | .0 | .95759E-01 | .41327 | .51904E-02 | .0 | 15.4051 |
| 13 | 315.33 | 14.696 | .0 | .30819E-01 | .0 | .0 | .0 | .95759E-01 | .41327 | .51904E-02 | .0 | 15.4051 |
| | 321.86 | 14.696 | .33312E-01 | .49546E-01 | .0 | .21838E-02 | .30904E-01 | .95759E-01 | .41327 | .51904E-02 | .0 | 17.2308 |
| 14 | 1110.8 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2308 |
| | 1110.8 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| 15 | 735.61 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| | 735.61 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| 16 | 554.02 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| | 554.02 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| | 554.02 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |
| | 554.02 | 14.696 | .0 | .82859E-01 | .0 | .0 | .33088E-01 | .78011E-01 | .41327 | .51904E-02 | .0 | 17.2309 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | ********** | 14.700 | .0 | .49632E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33088E-01 | 1.95436 |
| 103 | ********** | 14.700 | .0 | .49632E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33088E-01 | 1.95436 |
| 104 | 350.31 | 14.700 | .0 | .49632E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33088E-01 | 1.95436 |
| | 350.32 | 14.700 | .0 | .49632E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33088E-01 | 1.95436 |
| 105 | 365.97 | 14.700 | .97079E-01 | .18728E-01 | .0 | .21838E-02 | .30904E-01 | .0 | .0 | .0 | .0 | 1.95436 |
| 106 | 365.97 | 14.700 | .97079E-01 | .18728E-01 | .0 | .21838E-02 | .30904E-01 | .0 | .0 | .0 | .0 | 1.95436 |
| 107 | 357.04 | 14.700 | .33312E-01 | .18728E-01 | .0 | .21838E-02 | .30904E-01 | .0 | .0 | .0 | .0 | 1.82580 |
| 108 | 357.04 | 14.700 | .33312E-01 | .18728E-01 | .0 | .21838E-02 | .30904E-01 | .0 | .0 | .0 | .0 | 1.82580 |

| 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 357.03 | 14.696 | .0 | .58178 | .0 | .0 | .0 | 1.5900 | 6.9923 | .87818E-01 | .0 | 260.764 |
| | 357.03 | 14.696 | .0 | .58178 | .0 | .0 | .0 | 1.5900 | 6.9923 | .87818E-01 | .0 | 260.764 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 315.33 | 14.696 | .0 | .55096 | .0 | .0 | .0 | 1.7119 | 7.3883 | .92792E-01 | .0 | 275.405 |
| 7 | 330.14 | 14.696 | .0 | .55096 | .0 | .0 | .0 | 1.7119 | 7.3883 | .92792E-01 | .0 | 275.405 |
| 8 | 357.04 | 14.696 | .0 | .61473 | .0 | .0 | .0 | 1.6801 | 7.3883 | .92792E-01 | .0 | 275.533 |
| 9 | 357.03 | 14.696 | .0 | .61473 | .0 | .0 | .0 | 1.6801 | 7.3883 | .92792E-01 | .0 | 275.533 |
| 10 | 357.03 | 14.696 | .0 | .32961E-01 | .0 | .0 | .0 | .90082E-01 | .39615 | .49754E-02 | .0 | 14.7737 |
| 11 | 357.03 | 14.696 | .0 | .32961E-01 | .0 | .0 | .0 | .90082E-01 | .39615 | .49754E-02 | .0 | 14.7737 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 357.03 | 14.696 | .0 | .58177 | .0 | .0 | .0 | 1.5900 | 6.9921 | .87816E-01 | .0 | 260.760 |
| | 357.03 | 14.696 | .0 | .58177 | .0 | .0 | .0 | 1.5900 | 6.9921 | .87816E-01 | .0 | 260.760 |

NET AC POWER = 452.0 WATTS

HEATER POWER = 300.0 WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = -65.0 °F   RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 19.38 AMPS

DC VOLTAGE 57.56 VOLTS

SPECIFIC FUEL CONSUMPTION 2.34 LBS/KW-HR

BOL CELL PERFORMANCE

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# TABLE A-8

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .17717 | .65864 | .82720E-02 | .0 | 24.4524 |
| 2 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .17717 | .65864 | .82720E-02 | .0 | 24.4524 |
| 3 | 321.08 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.7827 | 7.7428 | .97243E-01 | .0 | 288.662 |
| 4 | 321.08 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.7827 | 7.7428 | .97243E-01 | .0 | 288.662 |
| 12 | 321.08 | 14.695 | .0 | .35229E-01 | .0 | .0 | .0 | .10467 | .45461 | .57095E-02 | .0 | 16.9485 |
| 13 | 321.08 | 14.695 | .0 | .35229E-01 | .0 | .0 | .0 | .10467 | .45461 | .57095E-02 | .0 | 16.9485 |
| | 325.22 | 14.696 | .27462E-01 | .50658E-01 | .0 | .17991E-02 | .25459E-01 | .10467 | .45461 | .57095E-02 | .0 | 18.4526 |
| 14 | 445.32 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4526 |
| | 445.32 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| 15 | 648.70 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| | 648.70 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| 16 | 507.54 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| | 507.54 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| | 507.54 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |
| | 507.54 | 14.696 | .0 | .78120E-01 | .0 | .0 | .27258E-01 | .90038E-01 | .45461 | .57095E-02 | .0 | 18.4527 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | ********** | 14.700 | .0 | .40887E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .27258E-01 | 1.61004 |
| 103 | ********** | 14.700 | .0 | .40887E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .27258E-01 | 1.61004 |
| 104 | 350.31 | 14.700 | .0 | .40887E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .27258E-01 | 1.61004 |
| | 350.32 | 14.700 | .0 | .40887E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .27258E-01 | 1.61004 |
| 105 | 359.84 | 14.700 | .79976E-01 | .15428E-01 | .0 | .17991E-02 | .25459E-01 | .0 | .0 | .0 | .0 | 1.61003 |
| 106 | 359.84 | 14.700 | .79976E-01 | .15428E-01 | .0 | .17991E-02 | .25459E-01 | .0 | .0 | .0 | .0 | 1.61003 |
| 107 | 355.07 | 14.700 | .27462E-01 | .15428E-01 | .0 | .17991E-02 | .25459E-01 | .0 | .0 | .0 | .0 | 1.50817 |
| 108 | 355.07 | 14.700 | .27462E-01 | .15428E-01 | .0 | .17991E-02 | .25459E-01 | .0 | .0 | .0 | .0 | 1.50817 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 355.06 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.6055 | 7.0842 | .88971E-01 | .0 | 264.209 |
| | 355.06 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.6055 | 7.0842 | .88971E-01 | .0 | 264.209 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 321.08 | 14.695 | .0 | .56479 | .0 | .0 | .0 | 1.6780 | 7.2882 | .91533E-01 | .0 | 271.713 |
| 7 | 336.05 | 14.695 | .0 | .56479 | .0 | .0 | .0 | 1.6780 | 7.2882 | .91533E-01 | .0 | 271.713 |
| 8 | 355.07 | 14.695 | .0 | .61730 | .0 | .0 | .0 | 1.6518 | 7.2882 | .91533E-01 | .0 | 271.819 |
| 9 | 355.06 | 14.695 | .0 | .61730 | .0 | .0 | .0 | 1.6518 | 7.2882 | .91533E-01 | .0 | 271.819 |
| 10 | 355.06 | 14.695 | .0 | .17278E-01 | .0 | .0 | .0 | .46232E-01 | .20399 | .25620E-02 | .0 | 7.60807 |
| 11 | 355.06 | 14.695 | .0 | .17278E-01 | .0 | .0 | .0 | .46232E-01 | .20399 | .25620E-02 | .0 | 7.60808 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 355.06 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.6055 | 7.0842 | .88971E-01 | .0 | 264.211 |
| | 355.06 | 14.695 | .0 | .60002 | .0 | .0 | .0 | 1.6055 | 7.0842 | .88971E-01 | .0 | 264.211 |

NET AC POWER = 300.0 WATTS

HEATER POWER = 300.0 WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = -65.0 °F RELATIVE HUMIDITY = 0 %

POWERSECTION CURRENT 15.96 AMPS

DC VOLTAGE 58.56 VOLTS

SPECIFIC FUEL CONSUMPTION 2.91 LBS/KW-HR

BOL CELL PERFORMANCE

AD-A055 900 UNITED TECHNOLOGIES CORP SOUTH WINDSOR CT POWER SYS--ETC F/G 10/2
PARAMETRIC ANALYSES OF 1.5-KW METHANOL FUEL CELL POWER PLANT DE--ETC(U)
MAY 78 A P MEYER, J A BETT, R A SEDERQUIST DAAK70-77-C-0195

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# TABLE A-9

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .22737 | .84523 | .10615E-01 | .0 | 31.3796 |
| 2 | ********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .22737 | .84523 | .10615E-01 | .0 | 31.3796 |
| 3 | 312.14 | 14.696 | .0 | .48969 | .0 | .0 | .0 | 1.8635 | 7.8389 | .98450E-01 | .0 | 292.011 |
| 4 | 312.14 | 14.696 | .0 | .48969 | .0 | .0 | .0 | 1.8638 | 7.8389 | .98450E-01 | .0 | 292.011 |
| 12 | 312.14 | 14.696 | .0 | .27665E-01 | .0 | .0 | .0 | .10530 | .44287 | .55621E-02 | .0 | 16.4976 |
| 13 | 312.14 | 14.696 | .0 | .27665E-01 | .0 | .0 | .0 | .10530 | .44287 | .55621E-02 | .0 | 16.4976 |
| | 317.93 | 14.696 | .29604E-01 | .44148E-01 | .0 | .19220E-02 | .27199E-01 | .10530 | .44287 | .55621E-02 | .0 | 18.1051 |
| 14 | 998.30 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 998.30 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| 15 | 676.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 676.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| 16 | 522.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 522.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 522.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 522.25 | 14.696 | .0 | .73752E-01 | .0 | .0 | .29121E-01 | .89535E-01 | .44287 | .55621E-02 | .0 | 18.1051 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | ********** | 14.700 | .0 | .43681E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .29121E-01 | 1.72006 |
| 103 | ********** | 14.700 | .0 | .43681E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .29121E-01 | 1.72006 |
| 104 | 350.31 | 14.700 | .0 | .43681E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .29121E-01 | 1.72006 |
| | 350.32 | 14.700 | .0 | .43681E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .29121E-01 | 1.72006 |
| 105 | 361.64 | 14.700 | .85441E-01 | .16482E-01 | .0 | .19220E-02 | .27199E-01 | .0 | .0 | .0 | .0 | 1.72005 |
| 106 | 361.64 | 14.700 | .85441E-01 | .16482E-01 | .0 | .19220E-02 | .27199E-01 | .0 | .0 | .0 | .0 | 1.72005 |
| 107 | 355.60 | 14.700 | .29604E-01 | .16482E-01 | .0 | .19220E-02 | .27199E-01 | .0 | .0 | .0 | .0 | 1.60749 |
| 108 | 355.60 | 14.700 | .29604E-01 | .16482E-01 | .0 | .19220E-02 | .27199E-01 | .0 | .0 | .0 | .0 | 1.60749 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 355.60 | 14.696 | .0 | .48969 | .0 | .0 | .0 | 1.6364 | 6.9937 | .87835E-01 | .0 | 260.632 |
| | 355.60 | 14.696 | .0 | .48969 | .0 | .0 | .0 | 1.6364 | 6.9937 | .87835E-01 | .0 | 260.632 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 312.14 | 14.696 | .0 | .46202 | .0 | .0 | .0 | 1.7565 | 7.3961 | .92888E-01 | .0 | 275.514 |
| 7 | 334.44 | 14.696 | .0 | .46202 | .0 | .0 | .0 | 1.7565 | 7.3961 | .92888E-01 | .0 | 275.514 |
| 8 | 355.60 | 14.696 | .0 | .51786 | .0 | .0 | .0 | 1.7306 | 7.3961 | .92888E-01 | .0 | 275.626 |
| 9 | 355.60 | 14.696 | .0 | .51786 | .0 | .0 | .0 | 1.7306 | 7.3961 | .92888E-01 | .0 | 275.626 |
| 10 | 355.60 | 14.696 | .0 | .28184E-01 | .0 | .0 | .0 | .94187E-01 | .40253 | .50554E-02 | .0 | 15.0010 |
| 11 | 355.60 | 14.696 | .0 | .28184E-01 | .0 | .0 | .0 | .94187E-01 | .40253 | .50554E-02 | .0 | 15.0010 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 355.60 | 14.696 | .0 | .48967 | .0 | .0 | .0 | 1.6364 | 6.9935 | .87833E-01 | .0 | 260.625 |
| | 355.60 | 14.696 | .0 | .48967 | .0 | .0 | .0 | 1.6364 | 6.9935 | .87833E-01 | .0 | 260.626 |

NET AC POWER = 197.0 WATTS

HEATER POWER = 450.0 WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = -65.0 °F    RELATIVE HUMIDITY = 0. %

POWERSECTION CURRENT 16.97 AMPS

DC VOLTAGE 58.37 VOLTS

SPECIFIC FUEL CONSUMPTION 4.73 LBS/KW-HR

BOL CELL PERFORMANCE

# TABLE A-10

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .20257 | .75306 | .94578E-02 | .0 | 27.9577 |
| 2 | *********** | 14.696 | .0 | .0 | .0 | .0 | .0 | .20257 | .75306 | .94578E-02 | .0 | 27.9577 |
| 3 | 315.59 | 14.696 | .0 | .48607 | .0 | .0 | .0 | 1.8563 | 7.8040 | .98013E-01 | .0 | 290.712 |
| 4 | 315.59 | 14.696 | .0 | .48607 | .0 | .0 | .0 | 1.8563 | 7.8040 | .98013E-01 | .0 | 290.712 |
| 12 | 315.59 | 14.696 | .0 | .29522E-01 | .0 | .0 | .0 | .11275 | .47398 | .59529E-02 | .0 | 17.6566 |
| 13 | 315.59 | 14.696 | .0 | .29522E-01 | .0 | .0 | .0 | .11275 | .47398 | .59529E-02 | .0 | 17.6567 |
| | 319.93 | 14.696 | .25985E-01 | .43981E-01 | .0 | .16814E-02 | .23795E-01 | .11275 | .47398 | .59529E-02 | .0 | 19.0631 |
| 14 | 394.82 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| | 394.82 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| 15 | 622.43 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| | 622.43 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| 16 | 493.57 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| | 493.57 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| | 493.57 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |
| | 493.57 | 14.696 | .0 | .69926E-01 | .0 | .0 | .25476E-01 | .98913E-01 | .47398 | .59529E-02 | .0 | 19.0631 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | *********** | 14.700 | .0 | .38214E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .25476E-01 | 1.50478 |
| 103 | *********** | 14.700 | .0 | .38214E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .25476E-01 | 1.50478 |
| 104 | 550.31 | 14.700 | .0 | .38214E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .25476E-01 | 1.50478 |
| | 550.32 | 14.700 | .0 | .38214E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .25476E-01 | 1.50478 |
| 105 | 357.82 | 14.700 | .74747E-01 | .14419E-01 | .0 | .16814E-02 | .23795E-01 | .0 | .0 | .0 | .0 | 1.50477 |
| 106 | 357.82 | 14.700 | .74747E-01 | .14419E-01 | .0 | .16814E-02 | .23795E-01 | .0 | .0 | .0 | .0 | 1.50477 |
| 107 | 354.38 | 14.700 | .25985E-01 | .14419E-01 | .0 | .16814E-02 | .23795E-01 | .0 | .0 | .0 | .0 | 1.40647 |
| 108 | 354.38 | 14.700 | .25985E-01 | .14419E-01 | .0 | .16814E-02 | .23795E-01 | .0 | .0 | .0 | .0 | 1.40647 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 354.38 | 14.696 | .0 | .48607 | .0 | .0 | .0 | 1.6538 | 7.0510 | .88555E-01 | .0 | 262.754 |
| | 354.38 | 14.696 | .0 | .48607 | .0 | .0 | .0 | 1.6538 | 7.0510 | .88555E-01 | .0 | 262.754 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 315.59 | 14.696 | .0 | .45655 | .0 | .0 | .0. | 1.7436 | 7.3300 | .92060E-01 | .0 | 273.055 |
| 7 | 358.10 | 14.696 | .0 | .45655 | .0 | .0 | .0 | 1.7436 | 7.3300 | .92060E-01 | .0 | 273.055 |
| 8 | 354.38 | 14.696 | .0 | .50531 | .0 | .0 | .0 | 1.7192 | 7.3300 | .92060E-01 | .0 | 273.153 |
| 9 | 354.37 | 14.696 | .0 | .50531 | .0 | .0 | .0 | 1.7192 | 7.3300 | .92060E-01 | .0 | 273.153 |
| 10 | 354.37 | 14.696 | .0 | .19256E-01 | .0 | .0 | .0 | .65514E-01 | .27932 | .35081E-02 | .0 | 10.4090 |
| 11 | 354.36 | 14.696 | .0 | .19256E-01 | .0 | .0 | .0 | .65514E-01 | .27932 | .35081E-02 | .0 | 10.4090 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 354.37 | 14.696 | .0 | .48605 | .0 | .0 | .0 | 1.6537 | 7.0507 | .88552E-01 | .0 | 262.744 |
| | 354.38 | 14.696 | .0 | .48605 | .0 | .0 | .0 | 1.6537 | 7.0507 | .88552E-01 | .0 | 262.744 |

NET AC POWER = 100.0 WATTS

HEATER POWER = 450.0 WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = -65.0 °F  RELATIVE HUMIDITY = 0 %

POWERSECTION CURRENT 14.82 AMPS

DC VOLTAGE 59.04 VOLTS

SPECIFIC FUEL CONSUMPTION 8.15 LBS/KW-HR

BOL CELL PERFORMANCE

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# TABLE A-11

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | •••••••••• | 14.696 | .0 | .0 | .0 | .0 | .0 | .17810 | .66210 | .03155E-02 | .0 | 24.5809 |
| 2 | •••••••••• | 14.696 | .0 | .0 | .0 | .0 | .0 | .17810 | .66210 | .03155E-02 | .0 | 24.5809 |
| 3 | 319.00 | 14.695 | .0 | .47857 | .0 | .0 | .0 | 1.8506 | 7.7695 | .97579E-01 | .0 | 289.809 |
| 4 | 319.00 | 14.695 | .0 | .47857 | .0 | .0 | .0 | 1.8506 | 7.7695 | .97579E-01 | .0 | 289.809 |
| 12 | 319.00 | 14.695 | .0 | .31734E-01 | .0 | .0 | .0 | .12271 | .51519 | .64704E-02 | .0 | 19.1905 |
| 13 | 319.00 | 14.695 | .0 | .31734E-01 | .0 | .0 | .0 | .12271 | .51519 | .64704E-02 | .0 | 19.1905 |
| | 322.09 | 14.695 | .22377E-01 | .44079E-01 | .0 | .14396E-02 | .20372E-01 | .12271 | .51519 | .64704E-02 | .0 | 20.3949 |
| 14 | 790.98 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| | 790.98 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| 15 | 569.11 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| | 569.11 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| 16 | 465.28 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| | 465.28 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| | 465.28 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |
| | 465.28 | 14.695 | .0 | .66456E-01 | .0 | .0 | .21012E-01 | .11080 | .51519 | .64704E-02 | .0 | 20.3949 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | •••••••••• | 14.700 | .0 | .32718E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21012E-01 | 1.20033 |
| 103 | •••••••••• | 14.700 | .0 | .32718E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21012E-01 | 1.20033 |
| 104 | 350.31 | 14.700 | .0 | .32718E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21012E-01 | 1.20033 |
| | 350.32 | 14.700 | .0 | .32718E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21012E-01 | 1.20033 |
| 105 | 354.01 | 14.700 | .63996E-01 | .12345E-01 | .0 | .14396E-02 | .20372E-01 | .0 | .0 | .0 | .0 | 1.20033 |
| 106 | 354.01 | 14.700 | .63996E-01 | .12345E-01 | .0 | .14396E-02 | .20372E-01 | .0 | .0 | .0 | .0 | 1.20033 |
| 107 | 353.16 | 14.700 | .22377E-01 | .12345E-01 | .0 | .14396E-02 | .20372E-01 | .0 | .0 | .0 | .0 | 1.20443 |
| 108 | 353.16 | 14.700 | .22377E-01 | .12345E-01 | .0 | .14396E-02 | .20372E-01 | .0 | .0 | .0 | .0 | 1.20443 |

| 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 353.16 | 14.695 | .0 | .47857 | .0 | .0 | .0 | 1.6725 | 7.1074 | .89263E-01 | .0 | 264.828 |
| | 353.16 | 14.695 | .0 | .47857 | .0 | .0 | .0 | 1.6725 | 7.1074 | .89263E-01 | .0 | 264.828 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 319.00 | 14.695 | .0 | .44684 | .0 | .0 | .0 | 1.7279 | 7.2543 | .91108E-01 | .0 | 270.219 |
| 7 | 341.75 | 14.695 | .0 | .44684 | .0 | .0 | .0 | 1.7279 | 7.2543 | .91108E-01 | .0 | 270.219 |
| 8 | 353.16 | 14.695 | .0 | .48846 | .0 | .0 | .0 | 1.7071 | 7.2543 | .91108E-01 | .0 | 270.302 |
| 9 | 353.16 | 14.695 | .0 | .48846 | .0 | .0 | .0 | 1.7071 | 7.2543 | .91108E-01 | .0 | 270.302 |
| 10 | 353.16 | 14.695 | .0 | .10058E-01 | .0 | .0 | .0 | .35151E-01 | .14930 | .10760E-02 | .0 | 5.56592 |
| 11 | 353.16 | 14.695 | .0 | .10058E-01 | .0 | .0 | .0 | .35151E-01 | .14930 | .10760E-02 | .0 | 5.56593 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 353.16 | 14.695 | .0 | .47840 | .0 | .0 | .0 | 1.6719 | 7.1049 | .89232E-01 | .0 | 264.737 |
| | 353.16 | 14.695 | .0 | .47840 | .0 | .0 | .0 | 1.6719 | 7.1049 | .89232E-01 | .0 | 264.737 |

NET AC POWER = 0 WATTS

HEATER POWER = 450.0 WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AMB}$ = -65.0 °F RELATIVE HUMIDITY = 0 %

POWERSECTION CURRENT 12.65 AMPS

DC VOLTAGE 59.77 VOLTS

SPECIFIC FUEL CONSUMPTION NOT APPLICABLE

BOL CELL PERFORMANCE

TABLE A-12

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.512 | 14.696 | .0 | .33479E-01 | .0 | .0 | .0 | .55570 | 2.0650 | .25945E-01 | .0 | 77.2974 |
| 2 | 70.512 | 14.696 | .0 | .33479E-01 | .0 | .0 | .0 | .55570 | 2.0650 | .25945E-01 | .0 | 77.2974 |
| 3 | 295.97 | 14.696 | .0 | .49445 | .0 | .0 | .0 | 1.9618 | 7.9729 | .10013 | .0 | 299.059 |
| 4 | 295.97 | 14.696 | .0 | .49445 | .0 | .0 | .0 | 1.9618 | 7.9729 | .10013 | .0 | 299.059 |
| 12 | 295.97 | 14.696 | .0 | .10768E-01 | .0 | .0 | .0 | .74404E-01 | .30239 | .37978E-02 | .0 | 11.3425 |
| 13 | 295.97 | 14.696 | .0 | .10768E-01 | .0 | .0 | .0 | .74404E-01 | .30239 | .37978E-02 | .0 | 11.3425 |
| | 510.23 | 14.697 | .60984E-01 | .54200E-01 | .0 | .41419E-02 | .58614E-01 | .74404E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| 14 | 1045.4 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 1045.4 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| 15 | 1172.5 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 1172.5 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| 16 | 792.51 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 792.51 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 792.51 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 792.51 | 14.697 | .0 | .11528 | .0 | .0 | .62756E-01 | .41838E-01 | .30239 | .37978E-02 | .0 | 14.8010 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70.512 | 14.700 | .0 | .94134E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .62756E-01 | 3.70673 |
| 103 | 70.512 | 14.700 | .0 | .94134E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .62756E-01 | 3.70673 |
| 104 | 550.51 | 14.700 | .0 | .94134E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .62756E-01 | 3.70673 |
| | 550.32 | 14.700 | .0 | .94134E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .62756E-01 | 3.70673 |
| 105 | 599.97 | 14.700 | .18415 | .35520E-01 | .0 | .41419E-02 | .58614E-01 | .0 | .0 | .0 | .0 | 3.70673 |
| 106 | 599.97 | 14.700 | .18415 | .35520E-01 | .0 | .41419E-02 | .58614E-01 | .0 | .0 | .0 | .0 | 3.70673 |
| 107 | 509.09 | 14.700 | .60984E-01 | .35520E-01 | .0 | .41419E-02 | .58614E-01 | .0 | .0 | .0 | .0 | 3.45849 |
| 108 | 509.09 | 14.700 | .60984E-01 | .35520E-01 | .0 | .41419E-02 | .58614E-01 | .0 | .0 | .0 | .0 | 3.45849 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 509.08 | 14.696 | .0 | .46137 | .0 | .0 | .0 | 1.4061 | 5.9071 | .74188E-01 | .0 | 221.762 |
| | 509.08 | 14.696 | .0 | .46137 | .0 | .0 | .0 | 1.4061 | 5.9071 | .74188E-01 | .0 | 221.762 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 295.97 | 14.696 | .0 | .47608 | .0 | .0 | .0 | 1.8873 | 7.6705 | .96336E-01 | .0 | 287.717 |
| 7 | 295.97 | 14.696 | .0 | .47608 | .0 | .0 | .0 | 1.8873 | 7.6705 | .96336E-01 | .0 | 287.717 |
| 8 | 509.09 | 14.696 | .0 | .59921 | .0 | .0 | .0 | 1.8258 | 7.6705 | .96336E-01 | .0 | 287.965 |
| 9 | 509.08 | 14.696 | .0 | .59921 | .0 | .0 | .0 | 1.8258 | 7.6705 | .96336E-01 | .0 | 287.965 |
| 10 | 509.08 | 14.696 | .0 | .15785 | .0 | .0 | .0 | .41996 | 1.7645 | .22159E-01 | .0 | 66.2366 |
| 11 | 509.08 | 14.696 | .0 | .15785 | .0 | .0 | .0 | .41996 | 1.7645 | .22159E-01 | .0 | 66.2366 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 509.08 | 14.696 | .0 | .46139 | .0 | .0 | .0 | 1.4058 | 5.9062 | .74177E-01 | .0 | 221.728 |
| | 509.08 | 14.696 | .0 | .46139 | .0 | .0 | .0 | 1.4058 | 5.9062 | .74177E-01 | .0 | 221.729 |

NET AC POWER = 1500.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AVG}$ = 70.0 °F  RELATIVE HUMIDITY = 50.0 %

POWERSECTION CURRENT 37.92 AMPS

DC VOLTAGE 53.60 VOLTS

SPECIFIC FUEL CONSUMPTION 1.39 LBS/KW-HR

500 HR CELL PERFORMANCE

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## TABLE A-13

### 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .26991E-01 | .0 | .0 | .0 | .44800 | 1.6654 | .20917E-01 | .0 | 62.3162 |
| 2 | 70.312 | 14.696 | .0 | .26991E-01 | .0 | .0 | .0 | .44800 | 1.6654 | .20917E-01 | .0 | 62.3162 |
| 3 | 304.91 | 14.696 | .0 | .52714 | .0 | .0 | .0 | 1.9135 | 7.8563 | .98669E-01 | .0 | 294.773 |
| 4 | 304.91 | 14.696 | .0 | .52714 | .0 | .0 | .0 | 1.9135 | 7.8563 | .98669E-01 | .0 | 294.773 |
| 12 | 304.91 | 14.696 | .0 | .22425E-01 | .0 | .0 | .0 | .81401E-01 | .33421 | .41974E-02 | .0 | 12.5397 |
| 13 | 304.91 | 14.696 | .0 | .22425E-01 | .0 | .0 | .0 | .81401E-01 | .33421 | .41974E-02 | .0 | 12.5397 |
| | 320.66 | 14.697 | .50510E-01 | .52027E-01 | .0 | .34518E-02 | .48848E-01 | .81401E-01 | .33421 | .41974E-02 | .0 | 15.4213 |
| 14 | 1500.3 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4213 |
| | 1500.3 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| 15 | 1017.3 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| | 1017.3 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| 16 | 700.82 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| | 700.82 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| | 700.82 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| | 700.82 | 14.697 | .0 | .10254 | .0 | .0 | .52300E-01 | .54416E-01 | .33421 | .41974E-02 | .0 | 15.4214 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 101 | 70.312 | 14.700 | .0 | .78450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52300E-01 | 3.00916 |
| 103 | 70.312 | 14.700 | .0 | .78450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52300E-01 | 3.00916 |
| 104 | 350.31 | 14.700 | .0 | .78450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52300E-01 | 3.00916 |
| | 350.52 | 14.700 | .0 | .78450E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .52300E-01 | 3.00916 |
| 105 | 500.07 | 14.700 | .15345 | .29602E-01 | .0 | .34518E-02 | .48848E-01 | .0 | .0 | .0 | .0 | 3.00916 |
| 106 | 500.07 | 14.700 | .15345 | .29602E-01 | .0 | .34518E-02 | .48848E-01 | .0 | .0 | .0 | .0 | 3.00916 |
| 107 | 365.45 | 14.700 | .50510E-01 | .29602E-01 | .0 | .34518E-02 | .48848E-01 | .0 | .0 | .0 | .0 | 2.88165 |
| 108 | 365.45 | 14.700 | .50510E-01 | .29602E-01 | .0 | .34518E-02 | .48848E-01 | .0 | .0 | .0 | .0 | 2.88165 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 21 | 365.44 | 14.696 | .0 | .50015 | .0 | .0 | .0 | 1.4655 | 6.1909 | .77755E-01 | .0 | 232.457 |
| | 365.44 | 14.696 | .0 | .50015 | .0 | .0 | .0 | 1.4655 | 6.1909 | .77755E-01 | .0 | 232.457 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 5 | 304.91 | 14.696 | .0 | .50472 | .0 | .0 | .0 | 1.6321 | 7.5221 | .94472E-01 | .0 | 282.233 |
| 7 | 304.91 | 14.696 | .0 | .50472 | .0 | .0 | .0 | 1.6321 | 7.5221 | .94472E-01 | .0 | 282.233 |
| 8 | 365.45 | 14.696 | .0 | .60765 | .0 | .0 | .0 | 1.7806 | 7.5221 | .94472E-01 | .0 | 282.441 |
| 9 | 365.44 | 14.696 | .0 | .60765 | .0 | .0 | .0 | 1.7806 | 7.5221 | .94472E-01 | .0 | 282.441 |
| 10 | 365.44 | 14.696 | .0 | .10752 | .0 | .0 | .0 | .31558 | 1.3323 | .16733E-01 | .0 | 50.0250 |
| 11 | 365.44 | 14.696 | .0 | .10762 | .0 | .0 | .0 | .31538 | 1.3323 | .16733E-01 | .0 | 50.0250 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 20 | 365.44 | 14.696 | .0 | .50002 | .0 | .0 | .0 | 1.4653 | 6.1898 | .77739E-01 | .0 | 232.416 |
| | 365.44 | 14.696 | .0 | .50002 | .0 | .0 | .0 | 1.4653 | 6.1898 | .77739E-01 | .0 | 232.416 |

NET AC POWER = 1250.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

$T_{AMB}$ = 70.0 °F RELATIVE HUMIDITY = 50.0 %

POWERSECTION CURRENT 31.28 AMPS

DC VOLTAGE 54.61 VOLTS

SPECIFIC FUEL CONSUMPTION 1.34 LBS/KW-HR

500 HR CELL PERFORMANCE

TABLE A-14

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .20729E-01 | .0 | .0 | .0 | .34406 | 1.2790 | .16064E-01 | .0 | 47.0569 |
| 2 | 70.312 | 14.696 | .0 | .20729E-01 | .0 | .0 | .0 | .34406 | 1.2790 | .16064E-01 | .0 | 47.0569 |
| 3 | 315.49 | 14.696 | .0 | .56864 | .0 | .0 | .0 | 1.0624 | 7.7462 | .97286E-01 | .0 | 290.745 |
| 4 | 315.49 | 14.696 | .0 | .56864 | .0 | .0 | .0 | 1.0624 | 7.7462 | .97286E-01 | .0 | 290.745 |
| 12 | 315.49 | 14.696 | .0 | .27077E-01 | .0 | .0 | .0 | .86682E-01 | .36885 | .46325E-02 | .0 | 13.8444 |
| 13 | 315.49 | 14.696 | .0 | .27077E-01 | .0 | .0 | .0 | .86682E-01 | .36885 | .46325E-02 | .0 | 13.8444 |
| | 325.08 | 14.697 | .40531E-01 | .50972E-01 | .0 | .27864E-02 | .39431E-01 | .86682E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| 14 | 1322.4 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| | 1322.4 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| 15 | 869.88 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| | 869.88 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| 16 | 520.43 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| | 520.43 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| | 520.43 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |
| | 520.43 | 14.697 | .0 | .91505E-01 | .0 | .0 | .42218E-01 | .67023E-01 | .36885 | .46325E-02 | .0 | 16.1700 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 70.312 | 14.700 | .0 | .63326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42218E-01 | 2.49362 |
| 103 | 70.312 | 14.700 | .0 | .63326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42218E-01 | 2.49362 |
| 104 | 350.51 | 14.700 | .0 | .63326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42218E-01 | 2.49362 |
| | 350.32 | 14.700 | .0 | .63326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .42218E-01 | 2.49362 |
| 105 | 370.85 | 14.700 | .12567 | .23895E-01 | .0 | .27864E-02 | .39431E-01 | .0 | .0 | .0 | .0 | 2.49362 |
| 106 | 370.85 | 14.700 | .12567 | .23895E-01 | .0 | .27864E-02 | .39431E-01 | .0 | .0 | .0 | .0 | 2.49362 |
| 107 | 301.92 | 14.700 | .40531E-01 | .23895E-01 | .0 | .27864E-02 | .39431E-01 | .0 | .0 | .0 | .0 | 2.32562 |
| 108 | 301.92 | 14.700 | .40531E-01 | .23895E-01 | .0 | .27864E-02 | .39431E-01 | .0 | .0 | .0 | .0 | 2.32562 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 301.92 | 14.696 | .0 | .54791 | .0 | .0 | .0 | 1.5183 | 6.4672 | .81223E-01 | .0 | 242.886 |
| | 301.92 | 14.696 | .0 | .54791 | .0 | .0 | .0 | 1.5183 | 6.4672 | .81223E-01 | .0 | 242.886 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 315.49 | 14.696 | .0 | .54156 | .0 | .0 | .0 | 1.7737 | 7.3774 | .92654E-01 | .0 | 276.901 |
| 7 | 315.49 | 14.696 | .0 | .54156 | .0 | .0 | .0 | 1.7737 | 7.3774 | .92654E-01 | .0 | 276.901 |
| 8 | 301.92 | 14.696 | .0 | .62490 | .0 | .0 | .0 | 1.7321 | 7.3774 | .92654E-01 | .0 | 277.069 |
| 9 | 301.92 | 14.696 | .0 | .62490 | .0 | .0 | .0 | 1.7321 | 7.3774 | .92654E-01 | .0 | 277.069 |
| 10 | 301.92 | 14.696 | .0 | .77267E-01 | .0 | .0 | .0 | .21411 | .91196 | .11453E-01 | .0 | 34.2500 |
| 11 | 301.92 | 14.696 | .0 | .77267E-01 | .0 | .0 | .0 | .21411 | .91196 | .11453E-01 | .0 | 34.2501 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 301.92 | 14.696 | .0 | .54765 | .0 | .0 | .0 | 1.5179 | 6.4654 | .81200E-01 | .0 | 242.819 |
| | 301.92 | 14.696 | .0 | .54765 | .0 | .0 | .0 | 1.5179 | 6.4654 | .81200E-01 | .0 | 242.819 |

NET AC POWER = 1000.0 WATTS POWERSECTION CURRENT = 25.33 AMPS

HEATER POWER = 0. WATTS DC VOLTAGE = 55.70 VOLTS

INVERTER EFFICIENCY = 84.0 % SPECIFIC FUEL CONSUMPTION = 1.35 LBS/KW-HR

TAMB 70.0 °F RELATIVE HUMIDITY: 50.0 % CELL PERFORMANCE 500 HR

# TABLE A-15

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 1 | 70.312 | 14.696 | .0 | .14623E-01 | .0 | .0 | .0 | .24272 | .90230 | .11332E-01 | .0 | 33.7619 |
| 2 | 70.312 | 14.696 | .0 | .14623E-01 | .0 | .0 | .0 | .24272 | .90230 | .11332E-01 | .0 | 33.7619 |
| 3 | 325.83 | 14.696 | .0 | .65231 | .0 | .0 | .0 | 1.8015 | 7.6402 | .95955E-01 | .0 | 286.920 |
| 4 | 325.83 | 14.696 | .0 | .65231 | .0 | .0 | .0 | 1.8015 | 7.6402 | .95955E-01 | .0 | 286.920 |
| 12 | 325.83 | 14.696 | .0 | .33961E-01 | .0 | .0 | .0 | .96701E-01 | .41012 | .51507E-02 | .0 | 15.4015 |
| 13 | 325.83 | 14.696 | .0 | .33961E-01 | .0 | .0 | .0 | .96701E-01 | .41012 | .51507E-02 | .0 | 15.4015 |
| | 330.77 | 14.696 | .30936E-01 | .52297E-01 | .0 | .21404E-02 | .30290E-01 | .96701E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| 14 | 1069.6 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 1069.6 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| 15 | 724.11 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 724.11 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| 16 | 550.55 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 550.55 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 550.55 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 550.55 | 14.696 | .0 | .83233E-01 | .0 | .0 | .32431E-01 | .80162E-01 | .41012 | .51507E-02 | .0 | 17.1875 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70.312 | 14.700 | .0 | .48646E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32431E-01 | 1.91554 |
| 103 | 70.312 | 14.700 | .0 | .48646E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32431E-01 | 1.91554 |
| 104 | 350.31 | 14.700 | .0 | .48646E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32431E-01 | 1.91554 |
| | 350.32 | 14.700 | .0 | .48646E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .32431E-01 | 1.91554 |
| 105 | 366.21 | 14.700 | .95151E-01 | .10356E-01 | .0 | .21404E-02 | .30290E-01 | .0 | .0 | .0 | .0 | 1.91554 |
| 106 | 366.21 | 14.700 | .95151E-01 | .10356E-01 | .0 | .21404E-02 | .30290E-01 | .0 | .0 | .0 | .0 | 1.91554 |
| 107 | 358.49 | 14.700 | .30936E-01 | .10356E-01 | .0 | .21404E-02 | .30290E-01 | .0 | .0 | .0 | .0 | 1.78608 |
| 108 | 356.48 | 14.700 | .30936E-01 | .10356E-01 | .0 | .21404E-02 | .30290E-01 | .0 | .0 | .0 | .0 | 1.78608 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 356.48 | 14.696 | .0 | .61766 | .0 | .0 | .0 | 1.5580 | 6.7379 | .84623E-01 | .0 | 253.158 |
| | 356.48 | 14.696 | .0 | .61766 | .0 | .0 | .0 | 1.5580 | 6.7379 | .84623E-01 | .0 | 253.158 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 325.83 | 14.696 | .0 | .59836 | .0 | .0 | .0 | 1.7048 | 7.2301 | .90804E-01 | .0 | 271.519 |
| 7 | 325.83 | 14.696 | .0 | .59836 | .0 | .0 | .0 | 1.7048 | 7.2301 | .90804E-01 | .0 | 271.519 |
| 8 | 358.48 | 14.696 | .0 | .60258 | .0 | .0 | .0 | 1.6727 | 7.2301 | .90804E-01 | .0 | 271.648 |
| 9 | 350.48 | 14.696 | .0 | .60258 | .0 | .0 | .0 | 1.6727 | 7.2301 | .90804E-01 | .0 | 271.648 |
| 10 | 350.48 | 14.696 | .0 | .45326E-01 | .0 | .0 | .0 | .11463 | .49461 | .62118E-02 | .0 | 18.5832 |
| 11 | 350.47 | 14.696 | .0 | .45326E-01 | .0 | .0 | .0 | .11463 | .49461 | .62118E-02 | .0 | 18.5832 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 356.48 | 14.696 | .0 | .61725 | .0 | .0 | .0 | 1.5582 | 6.7355 | .84593E-01 | .0 | 253.065 |
| | 356.49 | 14.696 | .0 | .61725 | .0 | .0 | .0 | 1.5582 | 6.7355 | .84593E-01 | .0 | 253.065 |

NET AC POWER = 750.0 WATTS    POWERSECTION CURRENT = 19.52 AMPS

HEATER POWER = 0. WATTS    DC VOLTAGE = 57.04 VOLTS

INVERTER EFFICIENCY = 84.0 %    SPECIFIC FUEL CONSUMPTION = 1.38 LBS/KW-HR

TAMB 70.0 °F    RELATIVE HUMIDITY: 50.0 %    CELL PERFORMANCE 500 HR

# TABLE A-16

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .15567E-01 | .0 | .0 | .0 | .25838 | .96052 | .12063E-01 | .0 | 35.9404 |
| 2 | 70.312 | 14.696 | .0 | .15567E-01 | .0 | .0 | .0 | .25838 | .96052 | .12063E-01 | .0 | 35.9404 |
| 3 | 322.46 | 14.696 | .0 | .54424 | .0 | .0 | .0 | 1.8557 | 7.6788 | .96439E-01 | .0 | 288.168 |
| 4 | 322.46 | 14.696 | .0 | .54424 | .0 | .0 | .0 | 1.8557 | 7.6788 | .96439E-01 | .0 | 288.168 |
| 12 | 322.46 | 14.696 | .0 | .30693E-01 | .0 | .0 | .0 | .10465 | .43306 | .54388E-02 | .0 | 16.2516 |
| 13 | 322.46 | 14.696 | .0 | .30693E-01 | .0 | .0 | .0 | .10465 | .43306 | .54388E-02 | .0 | 16.2516 |
| | 327.00 | 14.697 | .27500E-01 | .46940E-01 | .0 | .18946E-02 | .26811E-01 | .10465 | .43306 | .54388E-02 | .0 | 17.8329 |
| 14 | 973.26 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8329 |
| | 973.26 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| 15 | 676.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| | 676.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| 16 | 522.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| | 522.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| | 522.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |
| | 522.24 | 14.697 | .0 | .74528E-01 | .0 | .0 | .28706E-01 | .89913E-01 | .43306 | .54388E-02 | .0 | 17.8330 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 70.312 | 14.700 | .0 | .43059E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .28706E-01 | 1.69554 |
| 103 | 70.312 | 14.700 | .0 | .43059E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .28706E-01 | 1.69554 |
| 104 | 350.31 | 14.700 | .0 | .43059E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .28706E-01 | 1.69554 |
| | 350.32 | 14.700 | .0 | .43059E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .28706E-01 | 1.69554 |
| 105 | 362.07 | 14.700 | .84223E-01 | .16287E-01 | .0 | .18946E-02 | .26811E-01 | .0 | .0 | .0 | .0 | 1.69553 |
| 106 | 362.07 | 14.700 | .84223E-01 | .16287E-01 | .0 | .18946E-02 | .26811E-01 | .0 | .0 | .0 | .0 | 1.69553 |
| 107 | 357.09 | 14.700 | .27500E-01 | .16287E-01 | .0 | .18946E-02 | .26811E-01 | .0 | .0 | .0 | .0 | 1.50136 |
| 108 | 357.09 | 14.700 | .27500E-01 | .16287E-01 | .0 | .18946E-02 | .26811E-01 | .0 | .0 | .0 | .0 | 1.50136 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 357.09 | 14.696 | .0 | .52867 | .0 | .0 | .0 | 1.5973 | 6.7183 | .84375E-01 | .0 | 252.228 |
| | 357.09 | 14.696 | .0 | .52867 | .0 | .0 | .0 | 1.5973 | 6.7183 | .84375E-01 | .0 | 252.228 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 322.46 | 14.696 | .0 | .51354 | .0 | .0 | .0 | 1.7510 | 7.2457 | .91000E-01 | .0 | 271.917 |
| 7 | 329.97 | 14.696 | .0 | .51354 | .0 | .0 | .0 | 1.7510 | 7.2457 | .91000E-01 | .0 | 271.917 |
| 8 | 357.09 | 14.696 | .0 | .57018 | .0 | .0 | .0 | 1.7227 | 7.2457 | .91000E-01 | .0 | 272.031 |
| 9 | 357.09 | 14.696 | .0 | .57018 | .0 | .0 | .0 | 1.7227 | 7.2457 | .91000E-01 | .0 | 272.031 |
| 10 | 357.09 | 14.696 | .0 | .41511E-01 | .0 | .0 | .0 | .12542 | .52752 | .66251E-02 | .0 | 19.8048 |
| 11 | 357.09 | 14.696 | .0 | .41511E-01 | .0 | .0 | .0 | .12542 | .52752 | .66251E-02 | .0 | 19.8048 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 357.09 | 14.696 | .0 | .52867 | .0 | .0 | .0 | 1.5973 | 6.7182 | .84375E-01 | .0 | 252.226 |
| | 357.09 | 14.696 | .0 | .52867 | .0 | .0 | .0 | 1.5973 | 6.7182 | .84375E-01 | .0 | 252.226 |

NET AC POWER = 500.0 WATTS
POWERSECTION CURRENT = 17.21 AMPS

HEATER POWER = 150.0 WATTS
DC VOLTAGE = 57.75 VOLTS

INVERTER EFFICIENCY = 85.0 %
SPECIFIC FUEL CONSUMPTION = 1.84 LBS/KW-HR

TAMB 70.0 °F
RELATIVE HUMIDITY: 50.0 %
CELL PERFORMANCE 500 HR

TABLE A-17

## 1.5-KW Army Methanol Powerplant with Premix Fuel

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70,312 | 14,696 | .0 | .13310E-01 | .0 | .0 | .0 | .22093 | .82130 | .10315E-01 | .0 | 30,7311 |
| 2 | 70,312 | 14,696 | .0 | .13310E-01 | .0 | .0 | .0 | .22093 | .82130 | .10315E-01 | .0 | 30,7311 |
| 3 | 326,23 | 14,696 | .0 | .55947 | .0 | .0 | .0 | 1,8376 | 7,6409 | .95965E-01 | .0 | 286,781 |
| 4 | 326,23 | 14,696 | .0 | .55947 | .0 | .0 | .0 | 1,8376 | 7,6409 | .95965E-01 | .0 | 286,781 |
| 12 | 326,23 | 14,696 | .0 | .33489E-01 | .0 | .0 | .0 | .10999 | .45737 | .57443E-02 | .0 | 17,1662 |
| 13 | 326,23 | 14,696 | .0 | .33489E-01 | .0 | .0 | .0 | .10999 | .45737 | .57443E-02 | .0 | 17,1662 |
| | 329,49 | 14,696 | .24003E-01 | .47635E-01 | .0 | .16495E-02 | .23343E-01 | .10999 | .45737 | .57443E-02 | .0 | 18,5429 |
| 14 | 876,69 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 876,69 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| 15 | 624,05 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 624,05 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| 16 | 494,42 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 494,42 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 494,42 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 494,42 | 14,696 | .0 | .71638E-01 | .0 | .0 | .24992E-01 | .97166E-01 | .45737 | .57443E-02 | .0 | 18,5429 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70,312 | 14,700 | .0 | .37489E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24992E-01 | 1,47620 |
| 103 | 70,312 | 14,700 | .0 | .37489E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24992E-01 | 1,47620 |
| 104 | 350,31 | 14,700 | .0 | .37489E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24992E-01 | 1,47620 |
| | 350,32 | 14,700 | .0 | .37489E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24992E-01 | 1,47620 |
| 105 | 358,13 | 14,700 | .73328E-01 | .14146E-01 | .0 | .16495E-02 | .23343E-01 | .0 | .0 | .0 | .0 | 1,47620 |
| 106 | 358,13 | 14,700 | .73328E-01 | .14146E-01 | .0 | .16495E-02 | .23343E-01 | .0 | .0 | .0 | .0 | 1,47620 |
| 107 | 355,82 | 14,700 | .24003E-01 | .14146E-01 | .0 | .16495E-02 | .23343E-01 | .0 | .0 | .0 | .0 | 1,37676 |
| 108 | 355,82 | 14,700 | .24003E-01 | .14146E-01 | .0 | .16495E-02 | .23343E-01 | .0 | .0 | .0 | .0 | 1,37676 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 355,81 | 14,696 | .0 | .54616 | .0 | .0 | .0 | 1.6166 | 6.8196 | .85650E-01 | .0 | 256.050 |
| | 355,81 | 14,696 | .0 | .54616 | .0 | .0 | .0 | 1.6166 | 6.8196 | .85650E-01 | .0 | 256.050 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 326,23 | 14,696 | .0 | .52598 | .0 | .0 | .0 | 1.7276 | 7.1835 | .90221E-01 | .0 | 269.615 |
| 7 | 333,79 | 14,696 | .0 | .52598 | .0 | .0 | .0 | 1.7276 | 7.1835 | .90221E-01 | .0 | 269.615 |
| 8 | 355,82 | 14,696 | .0 | .57531 | .0 | .0 | .0 | 1.7029 | 7.1835 | .90221E-01 | .0 | 269.718 |
| 9 | 355,81 | 14,696 | .0 | .57531 | .0 | .0 | .0 | 1.7029 | 7.1835 | .90221E-01 | .0 | 269.718 |
| 10 | 355,81 | 14,696 | .0 | .29177E-01 | .0 | .0 | .0 | .86364E-01 | .36432 | .45756E-02 | .0 | 13.6788 |
| 11 | 355,81 | 14,696 | .0 | .29177E-01 | .0 | .0 | .0 | .86364E-01 | .36432 | .45756E-02 | .0 | 13.6788 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 355,81 | 14,696 | .0 | .54613 | .0 | .0 | .0 | 1.6165 | 6.8192 | .85645E-01 | .0 | 256.035 |
| | 355,81 | 14,696 | .0 | .54613 | .0 | .0 | .0 | 1.6165 | 6.8192 | .85645E-01 | .0 | 256.035 |

Net AC Power = 400.0 Watts    Powersection Current = 14.99 Amps

Heater Power = 150.0 Watts    DC Voltage = 58.37 Volts

Inverter Efficiency = 89.0 %    Specific Fuel Consumption = 2.00 LBS/KW-HR

Tamb 70.0 °F    Relative Humidity: 50.0 %    Cell Performance 500HR

TABLE A-18

15-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70,312 | 14,696 | ,0 | ,11114E-01 | ,0 | ,0 | ,0 | ,18447 | ,68576 | ,86127E-02 | ,0 | 25,6596 |
| 2 | 70,312 | 14,696 | ,0 | ,11114E-01 | ,0 | ,0 | ,0 | ,18447 | ,68576 | ,86127E-02 | ,0 | 25,6596 |
| 3 | 329,90 | 14,696 | ,0 | ,57746 | ,0 | ,0 | ,0 | 1,0184 | 7,6041 | ,95502E-01 | ,0 | 285,442 |
| 4 | 329,90 | 14,696 | ,0 | ,57746 | ,0 | ,0 | ,0 | 1,0184 | 7,6041 | ,95502E-01 | ,0 | 285,442 |
| 12 | 329,90 | 14,696 | ,0 | ,37038E-01 | ,0 | ,0 | ,0 | ,11663 | ,48772 | ,61253E-02 | ,0 | 18,3078 |
| 13 | 329,90 | 14,696 | ,0 | ,37038E-01 | ,0 | ,0 | ,0 | ,11663 | ,48772 | ,61253E-02 | ,0 | 18,3078 |
| | 332,12 | 14,696 | ,20503E-01 | ,49121E-01 | ,0 | ,14091E-02 | ,19940E-01 | ,11663 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| 14 | 781,85 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 781,85 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| 15 | 573,43 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 573,43 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| 16 | 467,56 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 467,56 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 467,56 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 467,56 | 14,696 | ,0 | ,69625E-01 | ,0 | ,0 | ,21349E-01 | ,10567 | ,48772 | ,61253E-02 | ,0 | 19,4839 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70,312 | 14,700 | ,0 | ,32024E-01 | ,0 | ,0 | ,0 | ,0 | ,0 | ,0 | ,21349E-01 | 1,26103 |
| 103 | 70,312 | 14,700 | ,0 | ,32024E-01 | ,0 | ,0 | ,0 | ,0 | ,0 | ,0 | ,21349E-01 | 1,26103 |
| 104 | 350,31 | 14,700 | ,0 | ,32024E-01 | ,0 | ,0 | ,0 | ,0 | ,0 | ,0 | ,21349E-01 | 1,26103 |
| | 350,32 | 14,700 | ,0 | ,32024E-01 | ,0 | ,0 | ,0 | ,0 | ,0 | ,0 | ,21349E-01 | 1,26103 |
| 105 | 354,28 | 14,700 | ,62639E-01 | ,12084E-01 | ,0 | ,14091E-02 | ,19940E-01 | ,0 | ,0 | ,0 | ,0 | 1,26103 |
| 106 | 354,28 | 14,700 | ,62639E-01 | ,12084E-01 | ,0 | ,14091E-02 | ,19940E-01 | ,0 | ,0 | ,0 | ,0 | 1,26103 |
| 107 | 354,58 | 14,700 | ,20503E-01 | ,12084E-01 | ,0 | ,14091E-02 | ,19940E-01 | ,0 | ,0 | ,0 | ,0 | 1,17608 |
| 108 | 354,58 | 14,700 | ,20503E-01 | ,12084E-01 | ,0 | ,14091E-02 | ,19940E-01 | ,0 | ,0 | ,0 | ,0 | 1,17608 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 354,57 | 14,696 | ,0 | ,56635 | ,0 | ,0 | ,0 | 1,6339 | 6,9183 | ,86889E-01 | ,0 | 259,783 |
| | 354,57 | 14,696 | ,0 | ,56635 | ,0 | ,0 | ,0 | 1,6339 | 6,9183 | ,86889E-01 | ,0 | 259,783 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 329,90 | 14,696 | ,0 | ,54043 | ,0 | ,0 | ,0 | 1,7017 | 7,1164 | ,89376E-01 | ,0 | 267,134 |
| 7 | 337,52 | 14,696 | ,0 | ,54043 | ,0 | ,0 | ,0 | 1,7017 | 7,1164 | ,89376E-01 | ,0 | 267,134 |
| 8 | 354,58 | 14,696 | ,0 | ,58256 | ,0 | ,0 | ,0 | 1,6807 | 7,1164 | ,89376E-01 | ,0 | 267,219 |
| 9 | 354,57 | 14,696 | ,0 | ,58256 | ,0 | ,0 | ,0 | 1,6807 | 7,1164 | ,89376E-01 | ,0 | 267,219 |
| 10 | 354,57 | 14,696 | ,0 | ,16253E-01 | ,0 | ,0 | ,0 | ,46890E-01 | ,19854 | ,24936E-02 | ,0 | 7,45534 |
| 11 | 354,57 | 14,696 | ,0 | ,16253E-01 | ,0 | ,0 | ,0 | ,46890E-01 | ,19854 | ,24936E-02 | ,0 | 7,45534 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 354,57 | 14,696 | ,0 | ,56631 | ,0 | ,0 | ,0 | 1,6338 | 6,9170 | ,86883E-01 | ,0 | 259,764 |
| | 354,57 | 14,696 | ,0 | ,56631 | ,0 | ,0 | ,0 | 1,6338 | 6,9170 | ,86883E-01 | ,0 | 259,764 |

NET AC POWER = 300.0 WATTS    POWERSECTION CURRENT = 12.81 AMPS

HEATER POWER = 150.0 WATTS    DC VOLTAGE = 59.03 VOLTS

INVERTER EFFICIENCY = 84.0 %    SPECIFIC FUEL CONSUMPTION = 2.28 LBS/KW-HR

TAMB 70.0 °F    RELATIVE HUMIDITY: 50.0 %    CELL PERFORMANCE 500 HR

# TABLE A-19

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .16120E-01 | .0 | .0 | .0 | .26757 | .99469 | .12493E-01 | .0 | 37.2188 |
| 2 | 70.312 | 14.696 | .0 | .16120E-01 | .0 | .0 | .0 | .26757 | .99469 | .12493E-01 | .0 | 37.2188 |
| 3 | 319.76 | 14.696 | .0 | .46619 | .0 | .0 | .0 | 1.9032 | 7.7093 | .96824E-01 | .0 | 289.152 |
| 4 | 319.76 | 14.696 | .0 | .46619 | .0 | .0 | .0 | 1.9032 | 7.7093 | .96824E-01 | .0 | 289.152 |
| 12 | 319.76 | 14.696 | .0 | .28179E-01 | .0 | .0 | .0 | .11504 | .46599 | .58526E-02 | .0 | 17.4779 |
| 13 | 319.76 | 14.696 | .0 | .28179E-01 | .0 | .0 | .0 | .11504 | .46599 | .58526E-02 | .0 | 17.4779 |
| | 323.56 | 14.696 | .23557E-01 | .41886E-01 | .0 | .15984E-02 | .22619E-01 | .11504 | .46599 | .58526E-02 | .0 | 18.8125 |
| 14 | 856.58 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8125 |
| | 856.58 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| 15 | 613.22 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| | 613.22 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| 16 | 488.67 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| | 488.67 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| | 488.67 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| | 488.67 | 14.696 | .0 | .65443E-01 | .0 | .0 | .24218E-01 | .10246 | .46599 | .58526E-02 | .0 | 18.8126 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70.312 | 14.700 | .0 | .36326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24218E-01 | 1.43044 |
| 103 | 70.312 | 14.700 | .0 | .36326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24218E-01 | 1.43044 |
| 104 | 350.31 | 14.700 | .0 | .36326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24218E-01 | 1.43044 |
| | 350.32 | 14.700 | .0 | .36326E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24218E-01 | 1.43044 |
| 105 | 357.14 | 14.700 | .71055E-01 | .13707E-01 | .0 | .15984E-02 | .22619E-01 | .0 | .0 | .0 | .0 | 1.43044 |
| 106 | 357.14 | 14.700 | .71055E-01 | .13707E-01 | .0 | .15984E-02 | .22619E-01 | .0 | .0 | .0 | .0 | 1.43044 |
| 107 | 355.46 | 14.700 | .23557E-01 | .13707E-01 | .0 | .15984E-02 | .22619E-01 | .0 | .0 | .0 | .0 | 1.33468 |
| 108 | 355.46 | 14.700 | .23557E-01 | .13707E-01 | .0 | .15984E-02 | .22619E-01 | .0 | .0 | .0 | .0 | 1.33468 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT- | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 355.46 | 14.696 | .0 | .45007 | .0 | .0 | .0 | 1.6356 | 6.7146 | .84331E-01 | .0 | 251.933 |
| | 355.46 | 14.696 | .0 | .45007 | .0 | .0 | .0 | 1.6356 | 6.7146 | .84331E-01 | .0 | 251.933 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 319.76 | 14.696 | .0 | .43801 | .0 | .0 | .0 | 1.7881 | 7.2433 | .90971E-01 | .0 | 271.674 |
| 7 | 334.86 | 14.696 | .0 | .43801 | .0 | .0 | .0 | 1.7881 | 7.2433 | .90971E-01 | .0 | 271.674 |
| 8 | 355.46 | 14.696 | .0 | .48551 | .0 | .0 | .0 | 1.7644 | 7.2433 | .90971E-01 | .0 | 271.770 |
| 9 | 355.46 | 14.696 | .0 | .48551 | .0 | .0 | .0 | 1.7644 | 7.2433 | .90971E-01 | .0 | 271.770 |
| 10 | 355.46 | 14.696 | .0 | .35457E-01 | .0 | .0 | .0 | .12885 | .52898 | .66437E-02 | .0 | 19.8474 |
| 11 | 355.45 | 14.696 | .0 | .35457E-01 | .0 | .0 | .0 | .12885 | .52898 | .66437E-02 | .0 | 19.8475 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 355.46 | 14.696 | .0 | .45005 | .0 | .0 | .0 | 1.6355 | 6.7143 | .84328E-01 | .0 | 251.922 |
| | 355.46 | 14.696 | .0 | .45005 | .0 | .0 | .0 | 1.6355 | 6.7143 | .84328E-01 | .0 | 251.922 |

NET AC POWER = 226.0 WATTS — POWERSECTION CURRENT = 14.44 AMPS

HEATER POWER = 300.0 WATTS — DC VOLTAGE = 58.64 VOLTS

INVERTER EFFICIENCY = 84.0 % — SPECIFIC FUEL CONSUMPTION = 3.42 LBS/KW-HR

TAMB = 70.0 °F — RELATIVE HUMIDITY: 50.0 % — CELL PERFORMANCE 500 HR

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TABLE A-20

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .13388E-01 | .0 | .0 | .0 | .22222 | .82609 | .10375E-01 | .0 | 30.9102 |
| 2 | 70.312 | 14.696 | .0 | .13388E-01 | .0 | .0 | .0 | .22222 | .82609 | .10375E-01 | .0 | 30.9102 |
| 3 | 324.25 | 14.695 | .0 | .46564 | .0 | .0 | .0 | 1.8910 | 7.6645 | .96222E-01 | .0 | 287.473 |
| 4 | 324.25 | 14.695 | .0 | .46564 | .0 | .0 | .0 | 1.8910 | 7.6645 | .96222E-01 | .0 | 287.473 |
| 12 | 324.25 | 14.695 | .0 | .30933E-01 | .0 | .0 | .0 | .12562 | .50916 | .63921E-02 | .0 | 19.0972 |
| 13 | 324.25 | 14.695 | .0 | .30933E-01 | .0 | .0 | .0 | .12562 | .50916 | .63921E-02 | .0 | 19.0971 |
| | 326.67 | 14.695 | .19213E-01 | .42057E-01 | .0 | .12972E-02 | .18358E-01 | .12562 | .50916 | .63921E-02 | .0 | 20.1805 |
| 14 | 737.87 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 737.87 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| 15 | 550.11 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 550.11 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| 16 | 455.22 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 455.22 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 455.22 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 455.22 | 14.695 | .0 | .61270E-01 | .0 | .0 | .19655E-01 | .11537 | .50916 | .63921E-02 | .0 | 20.1805 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70.312 | 14.700 | .0 | .29482E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .19655E-01 | 1.16094 |
| 103 | 70.312 | 14.700 | .0 | .29482E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .19655E-01 | 1.16094 |
| 104 | 350.31 | 14.700 | .0 | .29482E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .19655E-01 | 1.16094 |
| | 350.32 | 14.700 | .0 | .29482E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .19655E-01 | 1.16094 |
| 105 | 352.32 | 14.700 | .57666E-01 | .11125E-01 | .0 | .12972E-02 | .18358E-01 | .0 | .0 | .0 | .0 | 1.16094 |
| 106 | 352.32 | 14.700 | .57666E-01 | .11125E-01 | .0 | .12972E-02 | .18358E-01 | .0 | .0 | .0 | .0 | 1.16094 |
| 107 | 353.91 | 14.700 | .19213E-01 | .11125E-01 | .0 | .12972E-02 | .18358E-01 | .0 | .0 | .0 | .0 | 1.08341 |
| 108 | 353.91 | 14.700 | .19213E-01 | .11125E-01 | .0 | .12972E-02 | .18358E-01 | .0 | .0 | .0 | .0 | 1.08341 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 353.90 | 14.694 | .0 | .45225 | .0 | .0 | .0 | 1.6688 | 6.8384 | .85847E-01 | .0 | 256.563 |
| | 353.90 | 14.694 | .0 | .45225 | .0 | .0 | .0 | 1.6688 | 6.8384 | .85847E-01 | .0 | 256.563 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 324.25 | 14.695 | .0 | .43470 | .0 | .0 | .0 | 1.7654 | 7.1553 | .89830E-01 | .0 | 268.376 |
| 7 | 339.53 | 14.695 | .0 | .43470 | .0 | .0 | .0 | 1.7654 | 7.1553 | .89830E-01 | .0 | 268.376 |
| 8 | 353.91 | 14.695 | .0 | .47316 | .0 | .0 | .0 | 1.7462 | 7.1553 | .89830E-01 | .0 | 268.453 |
| 9 | 353.90 | 14.695 | .0 | .47316 | .0 | .0 | .0 | 1.7462 | 7.1553 | .89830E-01 | .0 | 268.454 |
| 10 | 353.90 | 14.695 | .0 | .20958E-01 | .0 | .0 | .0 | .77330E-01 | .31688 | .39782E-02 | .0 | 11.8887 |
| 11 | 353.90 | 14.695 | .0 | .20958E-01 | .0 | .0 | .0 | .77330E-01 | .31688 | .39782E-02 | .0 | 11.8887 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 353.90 | 14.695 | .0 | .45220 | .0 | .0 | .0 | 1.6688 | 6.8385 | .85852E-01 | .0 | 256.565 |
| | 353.90 | 14.695 | .0 | .45220 | .0 | .0 | .0 | 1.6688 | 6.8385 | .85852E-01 | .0 | 256.565 |

NET AC POWER = 100.0 WATTS POWERSECTION CURRENT = 11.69 AMPS

HEATER POWER = 300.0 WATTS DC VOLTAGE = 59.59 VOLTS

INVERTER EFFICIENCY = 84.0 % SPECIFIC FUEL CONSUMPTION = 6.29 LBS/KW-HR

TAMB 70.0 °F RELATIVE HUMIDITY: 50.0 % CELL PERFORMANCE 500 HR

# TABLE A-21

## 1.5-KW Army Methanol Powerplant with Premix Fuel

| | T F | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 1 | 70,312 | 14,696 | .0 | .18968E-01 | .0 | .0 | .0 | .31484 | 1,1704 | .14699E-01 | .0 | 43,7933 |
| 2 | 70,312 | 14,696 | .0 | .18968E-01 | .0 | .0 | .0 | .31484 | 1,1704 | .14699E-01 | .0 | 43,7933 |
| 3 | 315,33 | 14,696 | .0 | .40094 | .0 | .0 | .0 | 1,9545 | 7,7773 | .97673E-01 | .0 | 291,557 |
| 4 | 315,33 | 14,696 | .0 | .40094 | .0 | .0 | .0 | 1,9545 | 7,7773 | .97673E-01 | .0 | 291,557 |
| 12 | 315,33 | 14,696 | .0 | .24434E-01 | .0 | .0 | .0 | .11911 | .47396 | .59524E-02 | .0 | 17,7679 |
| 13 | 315,33 | 14,696 | .0 | .24434E-01 | .0 | .0 | .0 | .11911 | .47396 | .59524E-02 | .0 | 17,7679 |
| | 317,62 | 14,696 | .23137E-01 | .37714E-01 | .0 | .15486E-02 | .21915E-01 | .11911 | .47396 | .59524E-02 | .0 | 19,0617 |
| 14 | 657,01 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 657,01 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| 15 | 602,71 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 602,71 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| 16 | 485,08 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 485,08 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 485,08 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 485,08 | 14,696 | .0 | .60851E-01 | .0 | .0 | .23464E-01 | .10677 | .47396 | .59524E-02 | .0 | 19,0617 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 70,312 | 14,700 | .0 | .35196E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23464E-01 | 1,38591 |
| 103 | 70,312 | 14,700 | .0 | .35196E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23464E-01 | 1,38591 |
| 104 | 550,31 | 14,700 | .0 | .35196E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23464E-01 | 1,38591 |
| | 550,32 | 14,700 | .0 | .35196E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23464E-01 | 1,38591 |
| 105 | 556,18 | 14,700 | .68843E-01 | .13281E-01 | .0 | .15486E-02 | .21915E-01 | .0 | .0 | .0 | .0 | 1,38591 |
| 106 | 556,18 | 14,700 | .68843E-01 | .13281E-01 | .0 | .15486E-02 | .21915E-01 | .0 | .0 | .0 | .0 | 1,38591 |
| 107 | 555,11 | 14,700 | .23137E-01 | .13281E-01 | .0 | .15486E-02 | .21915E-01 | .0 | .0 | .0 | .0 | 1,29377 |
| 108 | 555,11 | 14,700 | .23137E-01 | .13281E-01 | .0 | .15486E-02 | .21915E-01 | .0 | .0 | .0 | .0 | 1,29377 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 555,11 | 14,696 | .0 | .38197 | .0 | .0 | .0 | 1,6397 | 6,6069 | .82974E-01 | .0 | 247,763 |
| | 555,11 | 14,696 | .0 | .38197 | .0 | .0 | .0 | 1,6397 | 6,6069 | .82974E-01 | .0 | 247,763 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 515,33 | 14,696 | .0 | .37650 | .0 | .0 | .0 | 1,8354 | 7,3033 | .91721E-01 | .0 | 273,789 |
| 7 | 535,91 | 14,696 | .0 | .37650 | .0 | .0 | .0 | 1,8354 | 7,3033 | .91721E-01 | .0 | 273,789 |
| 8 | 555,11 | 14,696 | .0 | .42221 | .0 | .0 | .0 | 1,8125 | 7,3033 | .91721E-01 | .0 | 273,881 |
| 9 | 555,11 | 14,696 | .0 | .42221 | .0 | .0 | .0 | 1,8125 | 7,3033 | .91721E-01 | .0 | 273,881 |
| 10 | 555,11 | 14,696 | .0 | .40257E-01 | .0 | .0 | .0 | .17282 | .69635 | .87453E-02 | .0 | 26,1138 |
| 11 | 555,11 | 14,696 | .0 | .40257E-01 | .0 | .0 | .0 | .17282 | .69635 | .87453E-02 | .0 | 26,1138 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 555,11 | 14,696 | .0 | .38195 | .0 | .0 | .0 | 1,6397 | 6,6070 | .82976E-01 | .0 | 247,767 |
| | 555,11 | 14,696 | .0 | .38195 | .0 | .0 | .0 | 1,6397 | 6,6070 | .82976E-01 | .0 | 247,767 |

Net AC Power = 51.90 Watts — Powersection Current = 13.89 Amps

Heater Power = 450.0 Watts — DC Voltage = 58.87 Volts

Inverter Efficiency = 84.0 % — Specific Fuel Consumption = 14.97 LBS/KW-HR

Tamb 70.0 °F — Relative Humidity: 50.0 % — Cell Performance 500 HR

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TABLE A-22

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.312 | 14.696 | .0 | .17855E-01 | .0 | .0 | .0 | .29636 | 1.1017 | .13837E-01 | .0 | 41.2238 |
| 2 | 70.312 | 14.696 | .0 | .17855E-01 | .0 | .0 | .0 | .29636 | 1.1017 | .13837E-01 | .0 | 41.2238 |
| 3 | 315.14 | 14.696 | .0 | .39664 | .0 | .0 | .0 | 1.9518 | 7.7594 | .97452E-01 | .0 | 290.884 |
| 4 | 315.14 | 14.696 | .0 | .39664 | .0 | .0 | .0 | 1.9518 | 7.7594 | .97452E-01 | .0 | 290.884 |
| 12 | 315.14 | 14.696 | .0 | .25095E-01 | .0 | .0 | .0 | .12349 | .49092 | .61657E-02 | .0 | 18.4038 |
| 13 | 315.14 | 14.696 | .0 | .25095E-01 | .0 | .0 | .0 | .12349 | .49092 | .61657E-02 | .0 | 18.4038 |
| | 316.77 | 14.696 | .21362E-01 | .37315E-01 | .0 | .14249E-02 | .20160E-01 | .12349 | .49092 | .61657E-02 | .0 | 19.5944 |
| 14 | 788.19 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5944 |
| | 788.19 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| 15 | 576.69 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| | 576.69 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| 16 | 469.27 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| | 469.27 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| | 469.27 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |
| | 469.27 | 14.696 | .0 | .58676E-01 | .0 | .0 | .21589E-01 | .11210 | .49092 | .61657E-02 | .0 | 19.5943 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 70.312 | 14.700 | .0 | .32384E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21589E-01 | 1.27519 |
| 103 | 70.312 | 14.700 | .0 | .32384E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21589E-01 | 1.27519 |
| 104 | 350.31 | 14.700 | .0 | .32384E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21589E-01 | 1.27519 |
| | 350.32 | 14.700 | .0 | .32384E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .21589E-01 | 1.27519 |
| 105 | 354.20 | 14.700 | .63345E-01 | .12220E-01 | .0 | .14249E-02 | .20160E-01 | .0 | .0 | .0 | .0 | 1.27519 |
| 106 | 354.20 | 14.700 | .63345E-01 | .12220E-01 | .0 | .14249E-02 | .20160E-01 | .0 | .0 | .0 | .0 | 1.27519 |
| 107 | 354.48 | 14.700 | .21362E-01 | .12220E-01 | .0 | .14249E-02 | .20160E-01 | .0 | .0 | .0 | .0 | 1.19056 |
| 108 | 354.48 | 14.700 | .21362E-01 | .12220E-01 | .0 | .14249E-02 | .20160E-01 | .0 | .0 | .0 | .0 | 1.19056 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 354.47 | 14.696 | .0 | .37879 | .0 | .0 | .0 | 1.6555 | 6.6577 | .83616E-01 | .0 | 249.661 |
| | 354.47 | 14.696 | .0 | .37879 | .0 | .0 | .0 | 1.6555 | 6.6577 | .83616E-01 | .0 | 249.661 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 315.14 | 14.696 | .0 | .37155 | .0 | .0 | .0 | 1.8284 | 7.2685 | .91287E-01 | .0 | 272.480 |
| 7 | 337.81 | 14.696 | .0 | .37155 | .0 | .0 | .0 | 1.8284 | 7.2685 | .91287E-01 | .0 | 272.480 |
| 8 | 354.48 | 14.696 | .0 | .41353 | .0 | .0 | .0 | 1.8074 | 7.2685 | .91287E-01 | .0 | 272.565 |
| 9 | 354.47 | 14.696 | .0 | .41353 | .0 | .0 | .0 | 1.8074 | 7.2685 | .91287E-01 | .0 | 272.565 |
| 10 | 354.47 | 14.696 | .0 | .34732E-01 | .0 | .0 | .0 | .15180 | .61048 | .76672E-02 | .0 | 22.8927 |
| 11 | 354.47 | 14.696 | .0 | .34732E-01 | .0 | .0 | .0 | .15180 | .61048 | .76672E-02 | .0 | 22.8927 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 354.47 | 14.696 | .0 | .37880 | .0 | .0 | .0 | 1.6556 | 6.6580 | .83619E-01 | .0 | 249.672 |
| | 354.47 | 14.696 | .0 | .37880 | .0 | .0 | .0 | 1.6556 | 6.6580 | .83619E-01 | .0 | 249.672 |

NET AC POWER = 0. WATTS — POWERSECTION CURRENT = 12.76 AMPS

HEATER POWER = 450.0 WATTS — DC VOLTAGE = 59.25 VOLTS

INVERTER EFFICIENCY = 84.0 % — SPECIFIC FUEL CONSUMPTION = NOT APPLICABLE

TAMB 70.0 °F — RELATIVE HUMIDITY: 50.0 % — CELL PERFORMANCE 500 HR

TABLE A-23

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .47497 | .0 | .0 | .0 | .66765 | 2.5563 | .32106E-01,0 | | 103.462 |
| 2 | 125.31 | 14.696 | .0 | .47497 | .0 | .0 | .0 | .66765 | 2.5563 | .32106E-01,0 | | 103.462 |
| 3 | 200.28 | 14.696 | .0 | 1.6399 | .0 | .0 | .0 | 1.0698 | 7.4323 | .93345E-01,0 | | 301.331 |
| 4 | 200.28 | 14.696 | .0 | 1.6399 | .0 | .0 | .0 | 1.0598 | 7.4323 | .93345E-01,0 | | 301.331 |
| 12 | 200.28 | 14.696 | .0 | .58853E-01,0 | | .0 | .0 | .67100E-01,26672 | | .33498E-02,0 | | 10.6138 |
| 13 | 200.28 | 14.696 | .0 | .58853E-01,0 | | .0 | .0 | .67100E-01,26672 | | .33498E-02,0 | | 10.6138 |
| | 315.59 | 14.697 | .62907E-01 | .96284E-01,0 | | .43602E-02,61703E-01,.67100E-01,26672 | | | | .33498E-02,0 | | 14.4520 |
| 14 | 1055.6 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 1055.6 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| 15 | 1200.5 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 1200.5 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| 16 | 800.75 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 800.75 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 800.75 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 800.75 | 14.697 | .0 | .15915 | .0 | .0 | .66066E-01,35467E-01,26672 | | | .33498E-02,0 | | 14.4520 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 125.31 | 14.700 | .0 | .99095E-01,0 | | .0 | .0 | .0 | .0 | .0 | .66064E-01 | 3.90211 |
| 103 | 125.31 | 14.700 | .0 | .99095E-01,0 | | .0 | .0 | .0 | .0 | .0 | .66064E-01 | 3.90211 |
| 104 | 350.51 | 14.700 | .0 | .99095E-01,0 | | .0 | .0 | .0 | .0 | .0 | .66064E-01 | 3.90211 |
| | 350.52 | 14.700 | .0 | .99095E-01,0 | | .0 | .0 | .0 | .0 | .0 | .66064E-01 | 3.90211 |
| 105 | 404.65 | 14.700 | .14563 | .37392E-01,0 | | .43602E-02,61703E-01,0 | | | .0 | .0 | .0 | 3.90211 |
| 106 | 404.55 | 14.700 | .14563 | .37392E-01,0 | | .43602E-02,61703E-01,0 | | | .0 | .0 | .0 | 3.90211 |
| 107 | 370.99 | 14.700 | .62907E-01 | .37392E-01,0 | | .43602E-02,61703E-01,0 | | | .0 | .0 | .0 | 3.63817 |
| 108 | 370.99 | 14.700 | .62907E-01 | .37392E-01,0 | | .43602E-02,61703E-01,0 | | | .0 | .0 | .0 | 3.63817 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 370.99 | 14.696 | .0 | 1.1650 | .0 | .0 | .0 | 1.1821 | 4.8760 | .61239E-01,0 | | 197.869 |
| | 370.99 | 14.696 | .0 | 1.1650 | .0 | .0 | .0 | 1.1521 | 4.6760 | .61239E-01,0 | | 197.869 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 285.28 | 14.696 | .0 | 1.5811 | .0 | .0 | .0 | 1.6027 | 7.1650 | .89995E-01,0 | | 290.517 |
| 7 | 285.28 | 14.696 | .0 | 1.5811 | .0 | .0 | .0 | 1.5027 | 7.1650 | .89995E-01,0 | | 290.517 |
| 8 | 370.99 | 14.696 | .0 | 1.7120 | .0 | .0 | .0 | 1.7372 | 7.1650 | .89995E-01,0 | | 290.781 |
| 9 | 370.98 | 14.696 | .0 | 1.7120 | .0 | .0 | .0 | 1.7372 | 7.1650 | .89995E-01,0 | | 290.781 |
| 10 | 370.96 | 14.696 | .0 | .54708 | .0 | .0 | .0 | .55509 | 2.2896 | .28756E-01,0 | | 92.9124 |
| 11 | 370.96 | 14.696 | .0 | .54708 | .0 | .0 | .0 | .55509 | 2.2896 | .28756E-01,0 | | 92.9124 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 370.98 | 14.696 | .0 | 1.1650 | .0 | .0 | .0 | 1.1821 | 4.8760 | .61239E-01,0 | | 197.868 |
| | 370.99 | 14.696 | .0 | 1.1650 | .0 | .0 | .0 | 1.1821 | 4.6760 | .61239E-01,0 | | 197.869 |

NET AC POWER = 1500. WATTS    POWERSECTION CURRENT = 39.79 AMPS

HEATER POWER = 0. WATTS    DC VOLTAGE = 50.41 VOLTS

INVERTER EFFICIENCY = 84.0 %    SPECIFIC FUEL CONSUMPTION = 1.41 LBS/KW-HR

TAMB = 125.0 °F    RELATIVE HUMIDITY: 95.0 %    CELL PERFORMANCE 6000 HR

# TABLE A-24

## 1.5-KW Army Methanol Powerplant with Premix Fuel

| Run | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 1 | 125.31 | 14.696 | .0 | .38611 | .0 | .0 | .0 | .55901 | 2.0781 | .26099E-01 | .0 | 84.1067 |
| 2 | 125.31 | 14.696 | .0 | .38611 | .0 | .0 | .0 | .55901 | 2.0781 | .26099E-01 | .0 | 84.1067 |
| 3 | 300.03 | 14.696 | .0 | 1.6463 | .0 | .0 | .0 | 1.8252 | 7.3178 | .91905E-01 | .0 | 296.750 |
| 4 | 300.03 | 14.696 | .0 | 1.6463 | .0 | .0 | .0 | 1.8252 | 7.3178 | .91905E-01 | .0 | 296.750 |
| 12 | 300.03 | 14.696 | .0 | .66230E-01 | .0 | .0 | .0 | .73426E-01 | .29440 | .36974E-02 | .0 | 11.9383 |
| 13 | 300.03 | 14.696 | .0 | .66230E-01 | .0 | .0 | .0 | .73426E-01 | .29440 | .36974E-02 | .0 | 11.9383 |
| | 516.14 | 14.697 | .51844E-01 | .97274E-01 | .0 | .36201E-02 | .51230E-01 | .73426E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| 14 | 1567.1 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 1567.1 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| 15 | 1039.5 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 1039.5 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| 16 | 719.38 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 719.38 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 719.38 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 719.38 | 14.697 | .0 | .14912 | .0 | .0 | .54850E-01 | .45692E-01 | .29440 | .36974E-02 | .0 | 14.9581 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 125.31 | 14.700 | .0 | .82275E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .54850E-01 | 3.23977 |
| 103 | 125.31 | 14.700 | .0 | .82275E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .54850E-01 | 3.23977 |
| 104 | 350.31 | 14.700 | .0 | .82275E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .54850E-01 | 3.23977 |
| | 350.32 | 14.700 | .0 | .82275E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .54850E-01 | 3.23977 |
| 105 | 391.59 | 14.700 | .16093 | .31045E-01 | .0 | .36201E-02 | .51230E-01 | .0 | .0 | .0 | .0 | 3.23976 |
| 106 | 391.59 | 14.700 | .16093 | .31045E-01 | .0 | .36201E-02 | .51230E-01 | .0 | .0 | .0 | .0 | 3.23976 |
| 107 | 367.07 | 14.700 | .51844E-01 | .31045E-01 | .0 | .36201E-02 | .51230E-01 | .0 | .0 | .0 | .0 | 3.01985 |
| 108 | 367.07 | 14.700 | .51844E-01 | .31045E-01 | .0 | .36201E-02 | .51230E-01 | .0 | .0 | .0 | .0 | 3.01985 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 367.06 | 14.696 | .0 | 1.2602 | .0 | .0 | .0 | 1.2662 | 5.2397 | .65806E-01 | .0 | 212.643 |
| | 367.06 | 14.696 | .0 | 1.2602 | .0 | .0 | .0 | 1.2662 | 5.2397 | .65806E-01 | .0 | 212.643 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 300.03 | 14.696 | .0 | 1.5800 | .0 | .0 | .0 | 1.7517 | 7.0234 | .88208E-01 | .0 | 284.811 |
| 7 | 300.03 | 14.696 | .0 | 1.5800 | .0 | .0 | .0 | 1.7517 | 7.0234 | .88208E-01 | .0 | 284.811 |
| 8 | 367.07 | 14.696 | .0 | 1.6891 | .0 | .0 | .0 | 1.6972 | 7.0234 | .88208E-01 | .0 | 285.031 |
| 9 | 367.06 | 14.696 | .0 | 1.6891 | .0 | .0 | .0 | 1.6972 | 7.0234 | .88208E-01 | .0 | 285.031 |
| 10 | 367.06 | 14.696 | .0 | .43007 | .0 | .0 | .0 | .45213 | 1.7882 | .22459E-01 | .0 | 72.5729 |
| 11 | 367.05 | 14.696 | .0 | .43007 | .0 | .0 | .0 | .45213 | 1.7882 | .22459E-01 | .0 | 72.5730 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 367.06 | 14.696 | .0 | 1.2590 | .0 | .0 | .0 | 1.2651 | 5.2351 | .65749E-01 | .0 | 212.458 |
| | 367.06 | 14.696 | .0 | 1.2590 | .0 | .0 | .0 | 1.2651 | 5.2351 | .65749E-01 | .0 | 212.458 |

Net AC Power = 1250.0 Watts  Powersection Current = 33.15 Amps

Heater Power = 0 Watts  DC Voltage = 51.54 Volts

Inverter Efficiency = 85.0 %  Specific Fuel Consumption = 1.50 LBS/KW-HR

Tamb 125.0 °F  Relative Humidity: 95.0 %  Cell Performance 1000 HR

TABLE A-25

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .29893 | .0 | .0 | .0 | .43278 | 1.6089 | .20206E-01 | .0 | 65.1152 |
| 2 | 125.31 | 14.696 | .0 | .29893 | .0 | .0 | .0 | .43278 | 1.6089 | .20206E-01 | .0 | 65.1152 |
| 3 | 311.51 | 14.696 | .0 | 1.6586 | .0 | .0 | .0 | 1.7782 | 7.2051 | .90490E-01 | .0 | 292.257 |
| 4 | 311.51 | 14.696 | .0 | 1.6586 | .0 | .0 | .0 | 1.7782 | 7.2051 | .90490E-01 | .0 | 292.257 |
| 12 | 311.51 | 14.696 | .0 | .74679E-01 | .0 | .0 | .0 | .80062E-01 | .32441 | .40743E-02 | .0 | 13.1587 |
| 13 | 311.51 | 14.696 | .0 | .74679E-01 | .0 | .0 | .0 | .80062E-01 | .32441 | .40743E-02 | .0 | 13.1587 |
| | 322.46 | 14.697 | .41344E-01 | .99599E-01 | .0 | .29058E-02 | .41122E-01 | .80062E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| 14 | 1327.1 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 1327.1 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| 15 | 660.54 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 660.54 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| 16 | 635.65 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 635.65 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 635.65 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 635.65 | 14.697 | .0 | .14094 | .0 | .0 | .44028E-01 | .57937E-01 | .32441 | .40743E-02 | .0 | 15.5822 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 125.31 | 14.700 | .0 | .66042E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .44028E-01 | 2.60055 |
| 103 | 125.31 | 14.700 | .0 | .66042E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .44028E-01 | 2.60055 |
| 104 | 350.31 | 14.700 | .0 | .66042E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .44028E-01 | 2.60055 |
| | 350.32 | 14.700 | .0 | .66042E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .44028E-01 | 2.60055 |
| 105 | 379.42 | 14.700 | .12918 | .24920E-01 | .0 | .29058E-02 | .41122E-01 | .0 | .0 | .0 | .0 | 2.60054 |
| 106 | 379.42 | 14.700 | .12918 | .24920E-01 | .0 | .29058E-02 | .41122E-01 | .0 | .0 | .0 | .0 | 2.60054 |
| 107 | 365.24 | 14.700 | .41344E-01 | .24920E-01 | .0 | .29058E-02 | .41122E-01 | .0 | .0 | .0 | .0 | 2.42347 |
| 108 | 365.25 | 14.700 | .41344E-01 | .24920E-01 | .0 | .29058E-02 | .41122E-01 | .0 | .0 | .0 | .0 | 2.42347 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 365.24 | 14.696 | .0 | 1.3597 | .0 | .0 | .0 | 1.3454 | 5.5962 | .70284E-01 | .0 | 227.142 |
| | 365.24 | 14.696 | .0 | 1.3597 | .0 | .0 | .0 | 1.3454 | 5.5962 | .70284E-01 | .0 | 227.142 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 311.51 | 14.696 | .0 | 1.5880 | .0 | .0 | .0 | 1.6981 | 6.8807 | .86416E-01 | .0 | 279.098 |
| 7 | 311.51 | 14.696 | .0 | 1.5880 | .0 | .0 | .0 | 1.6981 | 6.8807 | .86416E-01 | .0 | 279.098 |
| 8 | 365.24 | 14.696 | .0 | 1.6718 | .0 | .0 | .0 | 1.6542 | 6.8807 | .86416E-01 | .0 | 279.275 |
| 9 | 365.24 | 14.696 | .0 | 1.6718 | .0 | .0 | .0 | 1.6542 | 6.8807 | .86416E-01 | .0 | 279.275 |
| 10 | 365.24 | 14.696 | .0 | .31229 | .0 | .0 | .0 | .30901 | 1.2855 | .16143E-01 | .0 | 52.1691 |
| 11 | 365.24 | 14.696 | .0 | .31229 | .0 | .0 | .0 | .30901 | 1.2855 | .16143E-01 | .0 | 52.1691 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 365.24 | 14.696 | .0 | 1.3595 | .0 | .0 | .0 | 1.3452 | 5.5954 | .70273E-01 | .0 | 227.106 |
| | 365.24 | 14.696 | .0 | 1.3595 | .0 | .0 | .0 | 1.3452 | 5.5954 | .70273E-01 | .0 | 227.106 |

NET AC POWER = 1000.0 WATTS — POWERSECTION CURRENT = 26.69 AMPS

HEATER POWER = 0. WATTS — DC VOLTAGE = 52.85 VOLTS

INVERTER EFFICIENCY = 84.0 % — SPECIFIC FUEL CONSUMPTION = 1.51 LBS/KW-HR

TAMB 125.0 °F — RELATIVE HUMIDITY: 95.0 % — CELL PERFORMANCE 6000 HR

# TABLE A-26

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | IF | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 125.51 | 14.696 | .0 | .21509 | .0 | .0 | .0 | .51140 | 1.1576 | .14539E-01 | .0 | 46.8522 |
| 2 | | 125.51 | 14.696 | .0 | .21509 | .0 | .0 | .0 | .51140 | 1.1576 | .14539E-01 | .0 | 46.8522 |
| 3 | | 322.51 | 14.696 | .0 | 1.6839 | .0 | .0 | .0 | 1.7279 | 7.1010 | .89183E-01 | .0 | 288.134 |
| 4 | | 322.51 | 14.696 | .0 | 1.6839 | .0 | .0 | .0 | 1.7279 | 7.1010 | .89183E-01 | .0 | 288.134 |
| 12 | | 322.51 | 14.696 | .0 | .85064E-01 | .0 | .0 | .0 | .87289E-01 | .35875 | .45053E-02 | .0 | 14.5557 |
| 13 | | 322.51 | 14.696 | .0 | .85064E-01 | .0 | .0 | .0 | .87289E-01 | .35875 | .45053E-02 | .0 | 14.5557 |
| | | 328.29 | 14.696 | .31411E-01 | .10412 | .0 | .22226E-02 | .31453E-01 | .87289E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| 14 | | 1076.1 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | | 1076.1 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| 15 | | 742.58 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | | 742.58 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| 16 | | 557.81 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | | 557.81 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | | 557.81 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | | 557.81 | 14.696 | .0 | .13554 | .0 | .0 | .33676E-01 | .70472E-01 | .35875 | .45053E-02 | .0 | 16.4090 |
| | 2 | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 101 | | 125.51 | 14.700 | .0 | .50514E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33676E-01 | 1.98911 |
| 103 | | 125.51 | 14.700 | .0 | .50514E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33676E-01 | 1.98911 |
| 104 | | 350.31 | 14.700 | .0 | .50514E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33676E-01 | 1.98911 |
| | | 350.32 | 14.700 | .0 | .50514E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .33676E-01 | 1.98911 |
| 105 | | 367.97 | 14.700 | .98805E-01 | .19061E-01 | .0 | .22226E-02 | .31453E-01 | .0 | .0 | .0 | .0 | 1.98910 |
| 106 | | 367.97 | 14.700 | .98805E-01 | .19061E-01 | .0 | .22226E-02 | .31453E-01 | .0 | .0 | .0 | .0 | 1.98910 |
| 107 | | 359.58 | 14.700 | .31411E-01 | .19061E-01 | .0 | .22226E-02 | .31453E-01 | .0 | .0 | .0 | .0 | 1.85323 |
| 108 | | 359.59 | 14.700 | .31411E-01 | .19061E-01 | .0 | .22226E-02 | .31453E-01 | .0 | .0 | .0 | .0 | 1.85323 |
| | 3 | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| | 4 | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 21 | | 359.57 | 14.696 | .0 | 1.4688 | .0 | .0 | .0 | 1.4165 | 5.9434 | .74645E-01 | .0 | 241.281 |
| | | 359.57 | 14.696 | .0 | 1.4688 | .0 | .0 | .0 | 1.4165 | 5.9434 | .74645E-01 | .0 | 241.281 |
| | 5 | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 5 | | 322.51 | 14.696 | .0 | 1.5988 | .0 | .0 | .0 | 1.6406 | 6.7423 | .84678E-01 | .0 | 273.578 |
| 7 | | 322.51 | 14.696 | .0 | 1.5988 | .0 | .0 | .0 | 1.6406 | 6.7423 | .84678E-01 | .0 | 273.578 |
| 8 | | 359.58 | 14.696 | .0 | 1.6662 | .0 | .0 | .0 | 1.6069 | 6.7423 | .84678E-01 | .0 | 273.714 |
| 9 | | 359.57 | 14.696 | .0 | 1.6662 | .0 | .0 | .0 | 1.6069 | 6.7423 | .84678E-01 | .0 | 273.714 |
| 10 | | 359.57 | 14.696 | .0 | .19779 | .0 | .0 | .0 | .19075 | .80036 | .10052E-01 | .0 | 32.4916 |
| 11 | | 359.57 | 14.696 | .0 | .19779 | .0 | .0 | .0 | .19075 | .80036 | .10052E-01 | .0 | 32.4917 |
| | 6 | TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 20 | | 359.57 | 14.696 | .0 | 1.4684 | .0 | .0 | .0 | 1.4162 | 5.9419 | .74626E-01 | .0 | 241.222 |
| | | 359.57 | 14.696 | .0 | 1.4684 | .0 | .0 | .0 | 1.4162 | 5.9419 | .74626E-01 | .0 | 241.222 |

NET AC POWER = 750.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

TAMB 125.0 °F

POWERSECTION CURRENT = 20.43 AMPS

DC VOLTAGE = 54.35 VOLTS

SPECIFIC FUEL CONSUMPTION = [illegible] LBS/KW-HR

RELATIVE HUMIDITY: 95.0 % CELL PERFORMANCE [illegible] HR

TABLE A-27

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .13530 | .0 | .0 | .0 | .19588 | .72810 | .91454E-02 | .0 | 29.4718 |
| 2 | 125.31 | 14.696 | .0 | .13530 | .0 | .0 | .0 | .19588 | .72810 | .91454E-02 | .0 | 29.4718 |
| 3 | 332.94 | 14.696 | .0 | 1.7384 | .0 | .0 | .0 | 1.6653 | 7.0035 | .87959E-01 | .0 | 284.332 |
| 4 | 332.94 | 14.696 | .0 | 1.7384 | .0 | .0 | .0 | 1.6653 | 7.0035 | .87959E-01 | .0 | 284.332 |
| 12 | 332.94 | 14.696 | .0 | .10044 | .0 | .0 | .0 | .96209E-01 | .40462 | .50817E-02 | .0 | 16.4270 |
| 13 | 332.94 | 14.696 | .0 | .10044 | .0 | .0 | .0 | .96209E-01 | .40462 | .50817E-02 | .0 | 16.4270 |
| | 335.32 | 14.696 | .22033E-01 | .11590 | .0 | .15701E-02 | .22219E-01 | .96209E-01 | .40462 | .50817E-02 | .0 | 17.7358 |
| 14 | 454.03 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7358 |
| | 454.03 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| 15 | 507.80 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| | 507.80 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| 16 | 485.84 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| | 485.84 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| | 485.84 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| | 485.84 | 14.696 | .0 | .13593 | .0 | .0 | .23789E-01 | .84407E-01 | .40462 | .50817E-02 | .0 | 17.7359 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 101 | 125.51 | 14.700 | .0 | .35684E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23789E-01 | 1.40513 |
| 103 | 125.51 | 14.700 | .0 | .35684E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23789E-01 | 1.40513 |
| 104 | 550.31 | 14.700 | .0 | .35684E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23789E-01 | 1.40513 |
| | 550.32 | 14.700 | .0 | .35684E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .23789E-01 | 1.40513 |
| 105 | 557.28 | 14.700 | .69797E-01 | .13465E-01 | .0 | .15701E-02 | .22219E-01 | .0 | .0 | .0 | .0 | 1.40513 |
| 106 | 557.28 | 14.700 | .69797E-01 | .13465E-01 | .0 | .15701E-02 | .22219E-01 | .0 | .0 | .0 | .0 | 1.40513 |
| 107 | 556.11 | 14.700 | .22033E-01 | .13465E-01 | .0 | .15701E-02 | .22219E-01 | .0 | .0 | .0 | .0 | 1.30884 |
| 108 | 556.11 | 14.700 | .22033E-01 | .13465E-01 | .0 | .15701E-02 | .22219E-01 | .0 | .0 | .0 | .0 | 1.30884 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 21 | 556.11 | 14.696 | .0 | 1.6031 | .0 | .0 | .0 | 1.4694 | 6.2754 | .78813E-01 | .0 | 254.861 |
| | 556.11 | 14.696 | .0 | 1.6031 | .0 | .0 | .0 | 1.4694 | 6.2754 | .78813E-01 | .0 | 254.861 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 5 | 332.94 | 14.696 | .0 | 1.6380 | .0 | .0 | .0 | 1.5690 | 6.5989 | .82877E-01 | .0 | 267.905 |
| 7 | 332.94 | 14.696 | .0 | 1.6380 | .0 | .0 | .0 | 1.5690 | 6.5989 | .82877E-01 | .0 | 267.905 |
| 8 | 556.11 | 14.696 | .0 | 1.6858 | .0 | .0 | .0 | 1.5452 | 6.5989 | .82877E-01 | .0 | 268.001 |
| 9 | 556.11 | 14.696 | .0 | 1.6858 | .0 | .0 | .0 | 1.5452 | 6.5989 | .82877E-01 | .0 | 268.001 |
| 10 | 556.11 | 14.696 | .0 | .82979E-01 | .0 | .0 | .0 | .76058E-01 | .32482 | .40795E-02 | .0 | 13.1919 |
| 11 | 556.11 | 14.696 | .0 | .82979E-01 | .0 | .0 | .0 | .76058E-01 | .32482 | .40795E-02 | .0 | 13.1920 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 20 | 556.11 | 14.696 | .0 | 1.6028 | .0 | .0 | .0 | 1.4691 | 6.2741 | .78798E-01 | .0 | 254.809 |
| | 556.11 | 14.696 | .0 | 1.6028 | .0 | .0 | .0 | 1.4691 | 6.2741 | .78798E-01 | .0 | 254.809 |

NET AC POWER = 500.0 WATTS

HEATER POWER = 0. WATTS

INVERTER EFFICIENCY = 84.0 %

TAMB 125.0 °F

POWERSECTION CURRENT = 14.52 AMPS

DC VOLTAGE = 56.18 VOLTS

SPECIFIC FUEL CONSUMPTION = 1.52 LBS/KW-HR

RELATIVE HUMIDITY = 95.0 % CELL PERFORMANCE 6,000 HR

TABLE A-28

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .17948 | .0 | .0 | .0 | .25985 | .96597 | .12132E-01 | .0 | 39.0958 |
| 2 | 125.31 | 14.696 | .0 | .17948 | .0 | .0 | .0 | .25985 | .96597 | .12132E-01 | .0 | 39.0958 |
| 3 | 325.54 | 14.697 | .0 | 1.6401 | .0 | .0 | .0 | 1.7409 | 7.0763 | .88874E-01 | .0 | 287.053 |
| 4 | 325.54 | 14.697 | .0 | 1.6401 | .0 | .0 | .0 | 1.7409 | 7.0763 | .88874E-01 | .0 | 287.053 |
| 12 | 325.54 | 14.697 | .0 | .93687E-01 | .0 | .0 | .0 | .99444E-01 | .40422 | .50768E-02 | .0 | 16.3975 |
| 13 | 325.54 | 14.697 | .0 | .93687E-01 | .0 | .0 | .0 | .99444E-01 | .40422 | .50768E-02 | .0 | 16.3975 |
| | 326.79 | 14.697 | .22794E-01 | .10744 | .0 | .16034E-02 | .22691E-01 | .99444E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| 14 | 640.47 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| | 640.47 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| 15 | 614.59 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| | 614.59 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| 16 | 489.46 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| | 489.46 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| | 489.46 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |
| | 489.46 | 14.697 | .0 | .13023 | .0 | .0 | .24294E-01 | .87245E-01 | .40422 | .50768E-02 | .0 | 17.7347 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 125.31 | 14.700 | .0 | .36441E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24294E-01 | 1.43495 |
| 103 | 125.31 | 14.700 | .0 | .36441E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24294E-01 | 1.43495 |
| 104 | 350.31 | 14.700 | .0 | .36441E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24294E-01 | 1.43495 |
| | 350.32 | 14.700 | .0 | .36441E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .24294E-01 | 1.43495 |
| 105 | 357.67 | 14.700 | .71278E-01 | .13750E-01 | .0 | .16034E-02 | .22691E-01 | .0 | .0 | .0 | .0 | 1.43495 |
| 106 | 357.67 | 14.700 | .71278E-01 | .13750E-01 | .0 | .16034E-02 | .22691E-01 | .0 | .0 | .0 | .0 | 1.43495 |
| 107 | 350.20 | 14.700 | .22794E-01 | .13750E-01 | .0 | .16034E-02 | .22691E-01 | .0 | .0 | .0 | .0 | 1.33720 |
| 108 | 350.20 | 14.700 | .22794E-01 | .13750E-01 | .0 | .16034E-02 | .22691E-01 | .0 | .0 | .0 | .0 | 1.33720 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 356.19 | 14.697 | .0 | 1.4606 | .0 | .0 | .0 | 1.4810 | 6.1105 | .76742E-01 | .0 | 247.957 |
| | 350.19 | 14.697 | .0 | 1.4606 | .0 | .0 | .0 | 1.4810 | 6.1105 | .76742E-01 | .0 | 247.957 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 325.54 | 14.697 | .0 | 1.5464 | .0 | .0 | .0 | 1.6414 | 6.6720 | .83798E-01 | .0 | 270.656 |
| 7 | 352.66 | 14.697 | .0 | 1.5464 | .0 | .0 | .0 | 1.6414 | 6.6720 | .83798E-01 | .0 | 270.656 |
| 8 | 350.20 | 14.697 | .0 | 1.5949 | .0 | .0 | .0 | 1.6172 | 6.6720 | .83798E-01 | .0 | 270.753 |
| 9 | 356.19 | 14.697 | .0 | 1.5949 | .0 | .0 | .0 | 1.6172 | 6.6720 | .83798E-01 | .0 | 270.753 |
| 10 | 350.19 | 14.697 | .0 | .13431 | .0 | .0 | .0 | .13619 | .56189 | .70570E-02 | .0 | 22.8016 |
| 11 | 355.19 | 14.697 | .0 | .13431 | .0 | .0 | .0 | .13619 | .56189 | .70570E-02 | .0 | 22.8016 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 350.19 | 14.697 | .0 | 1.4606 | .0 | .0 | .0 | 1.4810 | 6.1102 | .76740E-01 | .0 | 247.952 |
| | 355.19 | 14.697 | .0 | 1.4606 | .0 | .0 | .0 | 1.4810 | 6.1102 | .76740E-01 | .0 | 247.952 |

NET AC POWER = 361.0 WATTS POWERSECTION CURRENT = 15.74 AMPS

HEATER POWER = 150.0 WATTS DC VOLTAGE = 56.23 VOLTS

INVERTER EFFICIENCY = 84.0 % SPECIFIC FUEL CONSUMPTION = 2.15 LBS/KW-HR

TAMB 125.0 °F RELATIVE HUMIDITY: 35.0 % CELL PERFORMANCE 6000 HR

# TABLE A-29

## 1.5-KW Army Methanol Powerplant with Premix Fuel

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .14644 | .0 | .0 | .0 | .21202 | .78817 | .98988E-02 | .0 | 31.0995 |
| 2 | 125.31 | 14.696 | .0 | .14644 | .0 | .0 | .0 | .21202 | .78817 | .98988E-02 | .0 | 31.0995 |
| 3 | 329.79 | 14.696 | .0 | 1.6464 | .0 | .0 | .0 | 1.7234 | 7.0369 | .88371E-01 | .0 | 285.487 |
| 4 | 329.79 | 14.696 | .0 | 1.6464 | .0 | .0 | .0 | 1.7234 | 7.0369 | .88371E-01 | .0 | 285.487 |
| 12 | 329.79 | 14.696 | .0 | .10136 | .0 | .0 | .0 | .10610 | .43322 | .54405E-02 | .0 | 17.5757 |
| 13 | 329.79 | 14.696 | .0 | .10136 | .0 | .0 | .0 | .10610 | .43322 | .54405E-02 | .0 | 17.5757 |
| | 331.88 | 14.696 | .16864E-01 | .11274 | .0 | .13265E-02 | .18772E-01 | .10610 | .43322 | .54405E-02 | .0 | 18.6820 |
| 14 | 743.59 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| | 743.59 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| 15 | 550.30 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| | 550.30 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| 16 | 459.58 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| | 459.58 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| | 459.58 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |
| | 459.58 | 14.696 | .0 | .13160 | .0 | .0 | .20099E-01 | .96003E-01 | .43322 | .54405E-02 | .0 | 18.6820 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 125.31 | 14.700 | .0 | .30148E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20099E-01 | 1.18715 |
| 103 | 125.31 | 14.700 | .0 | .30148E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20099E-01 | 1.18715 |
| 104 | 350.31 | 14.700 | .0 | .30148E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20099E-01 | 1.18715 |
| | 350.32 | 14.700 | .0 | .30148E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20099E-01 | 1.18715 |
| 105 | 353.20 | 14.700 | .58964E-01 | .11376E-01 | .0 | .13265E-02 | .18772E-01 | .0 | .0 | .0 | .0 | 1.18715 |
| 106 | 353.20 | 14.700 | .58964E-01 | .11376E-01 | .0 | .13265E-02 | .18772E-01 | .0 | .0 | .0 | .0 | 1.18715 |
| 107 | 354.76 | 14.700 | .18864E-01 | .11376E-01 | .0 | .13265E-02 | .18772E-01 | .0 | .0 | .0 | .0 | 1.10629 |
| 108 | 354.76 | 14.700 | .18864E-01 | .11376E-01 | .0 | .13265E-02 | .18772E-01 | .0 | .0 | .0 | .0 | 1.10629 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 354.76 | 14.696 | .0 | 1.5000 | .0 | .0 | .0 | 1.5114 | 6.2488 | .78472E-01 | .0 | 253.587 |
| | 354.76 | 14.696 | .0 | 1.5000 | .0 | .0 | .0 | 1.5114 | 6.2488 | .78472E-01 | .0 | 253.587 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 329.79 | 14.696 | .0 | 1.5451 | .0 | .0 | .0 | 1.6173 | 6.6037 | .82931E-01 | .0 | 267.911 |
| 7 | 330.97 | 14.696 | .0 | 1.5451 | .0 | .0 | .0 | 1.6173 | 6.6037 | .82931E-01 | .0 | 267.911 |
| 8 | 354.76 | 14.696 | .0 | 1.5852 | .0 | .0 | .0 | 1.5972 | 6.6037 | .82931E-01 | .0 | 267.991 |
| 9 | 354.76 | 14.696 | .0 | 1.5852 | .0 | .0 | .0 | 1.5972 | 6.6037 | .82931E-01 | .0 | 267.992 |
| 10 | 354.76 | 14.696 | .0 | .85135E-01 | .0 | .0 | .0 | .85783E-01 | .35467 | .44540E-02 | .0 | 14.3931 |
| 11 | 354.76 | 14.696 | .0 | .85135E-01 | .0 | .0 | .0 | .85783E-01 | .35467 | .44540E-02 | .0 | 14.3932 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 354.76 | 14.696 | .0 | 1.5000 | .0 | .0 | .0 | 1.5114 | 6.2491 | .78477E-01 | .0 | 253.599 |
| | 354.76 | 14.696 | .0 | 1.5000 | .0 | .0 | .0 | 1.5114 | 6.2491 | .78477E-01 | .0 | 253.599 |

Net AC Power = 250.0 Watts — Powersection Current = 12.19 Amps

Heater Power = 150.0 Watts — DC Voltage = 57.19 Volts

Inverter Efficiency = 84.0 % — Specific Fuel Consumption = 2.57 LBS/KW-HR

Tamb = 125.0 °F — Relative Humidity: 95.0 % — Cell Performance 6000 HR

TABLE A-30

1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .18765 | .0 | .0 | .0 | .27168 | 1.0100 | .12684E-01 | .0 | 40.8761 |
| 2 | 125.31 | 14.696 | .0 | .18765 | .0 | .0 | .0 | .27168 | 1.0100 | .12684E-01 | .0 | 40.8761 |
| 3 | 322.84 | 14.696 | .0 | 1.5767 | .0 | .0 | .0 | 1.7824 | 7.1035 | .89215E-01 | .0 | 288.019 |
| 4 | 322.84 | 14.696 | .0 | 1.5767 | .0 | .0 | .0 | 1.7824 | 7.1035 | .89215E-01 | .0 | 288.019 |
| 12 | 322.84 | 14.696 | .0 | .96464E-01 | .0 | .0 | .0 | .10905 | .83461 | .54585E-02 | .0 | 17.6218 |
| 13 | 322.84 | 14.696 | .0 | .96464E-01 | .0 | .0 | .0 | .10905 | .83461 | .54585E-02 | .0 | 17.6218 |
| | 525.53 | 14.696 | .19240E-01 | .10788 | .0 | .13317E-02 | .18845E-01 | .10905 | .83461 | .54585E-02 | .0 | 18.7330 |
| 14 | 745.33 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| | 745.33 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| 15 | 559.33 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| | 559.33 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| 16 | 400.13 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| | 400.13 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| | 400.13 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |
| | 400.13 | 14.696 | .0 | .12712 | .0 | .0 | .20177E-01 | .98769E-01 | .83461 | .54585E-02 | .0 | 18.7330 |

| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 101 | 125.31 | 14.700 | .0 | .30265E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20177E-01 | 1.19177 |
| 103 | 125.31 | 14.700 | .0 | .30265E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20177E-01 | 1.19177 |
| 104 | 350.31 | 14.700 | .0 | .30265E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20177E-01 | 1.19177 |
| | 350.32 | 14.700 | .0 | .30265E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .20177E-01 | 1.19177 |
| 105 | 353.12 | 14.700 | .59194E-01 | .11420E-01 | .0 | .13317E-02 | .18845E-01 | .0 | .0 | .0 | .0 | 1.19177 |
| 106 | 353.12 | 14.700 | .59194E-01 | .11420E-01 | .0 | .13317E-02 | .18845E-01 | .0 | .0 | .0 | .0 | 1.19177 |
| 107 | 354.70 | 14.700 | .19240E-01 | .11420E-01 | .0 | .13317E-02 | .18845E-01 | .0 | .0 | .0 | .0 | 1.11121 |
| 108 | 354.70 | 14.700 | .19240E-01 | .11420E-01 | .0 | .13317E-02 | .18845E-01 | .0 | .0 | .0 | .0 | 1.11121 |

| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 354.70 | 14.696 | .0 | 1.3890 | .0 | .0 | .0 | 1.5108 | 6.0936 | .76531E-01 | .0 | 247.143 |
| | 354.70 | 14.696 | .0 | 1.3890 | .0 | .0 | .0 | 1.5108 | 6.0936 | .76531E-01 | .0 | 247.143 |

| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 322.84 | 14.696 | .0 | 1.4802 | .0 | .0 | .0 | 1.6734 | 6.6689 | .83757E-01 | .0 | 270.397 |
| 7 | 337.15 | 14.696 | .0 | 1.4802 | .0 | .0 | .0 | 1.6734 | 6.6689 | .83757E-01 | .0 | 270.397 |
| 8 | 354.70 | 14.696 | .0 | 1.5201 | .0 | .0 | .0 | 1.6534 | 6.6689 | .83757E-01 | .0 | 270.478 |
| 9 | 354.70 | 14.696 | .0 | 1.5201 | .0 | .0 | .0 | 1.6534 | 6.6689 | .83757E-01 | .0 | 270.478 |
| 10 | 354.70 | 14.696 | .0 | .13120 | .0 | .0 | .0 | .14270 | .57556 | .72287E-02 | .0 | 23.3436 |
| 11 | 354.70 | 14.696 | .0 | .13120 | .0 | .0 | .0 | .14270 | .57556 | .72287E-02 | .0 | 23.3436 |

| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 354.70 | 14.696 | .0 | 1.3890 | .0 | .0 | .0 | 1.5107 | 6.0934 | .76528E-01 | .0 | 247.134 |
| | 354.70 | 14.696 | .0 | 1.3890 | .0 | .0 | .0 | 1.5107 | 6.0934 | .76528E-01 | .0 | 247.134 |

NET AC POWER = 99.0 WATTS    POWERSECTION CURRENT = 12.14 AMPS

HEATER POWER = 300.0 WATTS    DC VOLTAGE = 57.25 VOLTS

INVERTER EFFICIENCY = 84.0 %    SPECIFIC FUEL CONSUMPTION = 6.52 LBS/KW-HR

TAMB 125.0 °F    RELATIVE HUMIDITY: 89.0 %    CELL PERFORMANCE 6000 HR

# TABLE A-31

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .17368 | .0 | .0 | .0 | .25146 | .93079 | .11740E-01 | .0 | 37.8339 |
| 2 | 125.31 | 14.696 | .0 | .17368 | .0 | .0 | .0 | .25146 | .93079 | .11740E-01 | .0 | 37.8339 |
| 3 | 324.61 | 14.696 | .0 | 1.5720 | .0 | .0 | .0 | 1.7785 | 7.0885 | .89013E-01 | .0 | 287.378 |
| 4 | 324.61 | 14.696 | .0 | 1.5720 | .0 | .0 | .0 | 1.7785 | 7.0885 | .89013E-01 | .0 | 287.378 |
| 12 | 324.61 | 14.696 | .0 | .99993E-01 | .0 | .0 | .0 | .11313 | .45089 | .56620E-02 | .0 | 18.2799 |
| 13 | 324.61 | 14.696 | .0 | .99993E-01 | .0 | .0 | .0 | .11313 | .45089 | .56620E-02 | .0 | 18.2799 |
| | 326.83 | 14.696 | .17564E-01 | .11039 | .0 | .12125E-02 | .17158E-01 | .11313 | .45089 | .56620E-02 | .0 | 19.2917 |
| 14 | 700.98 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 700.98 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| 15 | 555.33 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 555.33 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| 16 | 447.43 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 447.43 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 447.43 | 14.596 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 447.43 | 14.696 | .0 | .12796 | .0 | .0 | .18371E-01 | .10374 | .45089 | .56620E-02 | .0 | 19.2917 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 101 | 125.31 | 14.700 | .0 | .27556E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .18371E-01 | 1.00510 |
| 103 | 125.31 | 14.700 | .0 | .27556E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .18371E-01 | 1.00510 |
| 104 | 350.31 | 14.700 | .0 | .27556E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .18371E-01 | 1.00510 |
| | 350.32 | 14.700 | .0 | .27556E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .18371E-01 | 1.00510 |
| 105 | 351.20 | 14.700 | .53900E-01 | .10398E-01 | .0 | .12125E-02 | .17158E-01 | .0 | .0 | .0 | .0 | 1.00510 |
| 106 | 351.20 | 14.700 | .53900E-01 | .10398E-01 | .0 | .12125E-02 | .17158E-01 | .0 | .0 | .0 | .0 | 1.00510 |
| 107 | 354.09 | 14.700 | .17564E-01 | .10398E-01 | .0 | .12125E-02 | .17158E-01 | .0 | .0 | .0 | .0 | 1.01185 |
| 108 | 354.09 | 14.700 | .17564E-01 | .10398E-01 | .0 | .12125E-02 | .17158E-01 | .0 | .0 | .0 | .0 | 1.01185 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 354.09 | 14.696 | .0 | 1.3985 | .0 | .0 | .0 | 1.5270 | 6.1537 | .77272E-01 | .0 | 249.545 |
| | 354.09 | 14.696 | .0 | 1.3983 | .0 | .0 | .0 | 1.5270 | 6.1537 | .77272E-01 | .0 | 249.545 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCU | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 324.61 | 14.696 | .0 | 1.4720 | .0 | .0 | .0 | 1.6654 | 6.6376 | .83351E-01 | .0 | 269.098 |
| 7 | 350.98 | 14.696 | .0 | 1.4720 | .0 | .0 | .0 | 1.6654 | 6.6376 | .83351E-01 | .0 | 269.098 |
| 8 | 354.09 | 14.696 | .0 | 1.5083 | .0 | .0 | .0 | 1.6472 | 6.6376 | .83351E-01 | .0 | 269.172 |
| 9 | 354.09 | 14.696 | .0 | 1.5083 | .0 | .0 | .0 | 1.6472 | 6.6376 | .83351E-01 | .0 | 269.172 |
| 10 | 354.09 | 14.696 | .0 | .10987 | .0 | .0 | .0 | .11999 | .48351 | .60716E-02 | .0 | 19.6077 |
| 11 | 354.09 | 14.696 | .0 | .10987 | .0 | .0 | .0 | .11999 | .48351 | .60716E-02 | .0 | 19.6077 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCU | MCU2 | MU2 | MN2 | MA | FUEL | PPH |
| 20 | 354.09 | 14.696 | .0 | 1.3985 | .0 | .0 | .0 | 1.5272 | 6.1541 | .77279E-01 | .0 | 249.564 |
| | 354.09 | 14.696 | .0 | 1.3985 | .0 | .0 | .0 | 1.5272 | 6.1541 | .77279E-01 | .0 | 249.564 |

NET AC POWER = 50.0 WATTS    POWERSECTION CURRENT = 11.09 AMPS

HEATER POWER = 300.0 WATTS    DC VOLTAGE = 57.68 VOLTS

INVERTER EFFICIENCY = 84.0 %    SPECIFIC FUEL CONSUMPTION = 11.76 LBS/KW-HR

TAMB 125.0 °F    RELATIVE HUMIDITY: 84.0 %    CELL PERFORMANCE 6030HR

# TABLE A-32

## 1.5-KW ARMY METHANOL POWERPLANT WITH PREMIX FUEL

| | 1 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 125.31 | 14.696 | .0 | .16000 | .0 | .0 | .0 | .23165 | .86114 | .10815E-01 | .0 | 34.8529 |
| 2 | 125.31 | 14.696 | .0 | .16000 | .0 | .0 | .0 | .23165 | .86114 | .10815E-01 | .0 | 34.8529 |
| 3 | 326.34 | 14.696 | .0 | 1.5665 | .0 | .0 | .0 | 1.7756 | 7.0725 | .88814E-01 | .0 | 286.731 |
| 4 | 326.34 | 14.696 | .0 | 1.5665 | .0 | .0 | .0 | 1.7756 | 7.0725 | .88814E-01 | .0 | 286.731 |
| 12 | 326.34 | 14.696 | .0 | .10424 | .0 | .0 | .0 | .11815 | .47061 | .59098E-02 | .0 | 19.0793 |
| 13 | 326.34 | 14.696 | .0 | .10424 | .0 | .0 | .0 | .11815 | .47061 | .59098E-02 | .0 | 19.0794 |
| | 328.12 | 14.696 | .15905E-01 | .11361 | .0 | .10931E-02 | .15469E-01 | .11815 | .47061 | .59098E-02 | .0 | 19.9917 |
| 14 | 656.62 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 656.62 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| 15 | 511.46 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 511.46 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| 16 | 434.84 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 434.84 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 434.84 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 434.84 | 14.696 | .0 | .12952 | .0 | .0 | .16562E-01 | .10965 | .47061 | .59098E-02 | .0 | 19.9917 |
| | 2 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 101 | 125.31 | 14.700 | .0 | .24843E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .16562E-01 | .978253 |
| 103 | 125.31 | 14.700 | .0 | .24843E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .16562E-01 | .978253 |
| 104 | 350.31 | 14.700 | .0 | .24843E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .16562E-01 | .978253 |
| | 350.32 | 14.700 | .0 | .24843E-01 | .0 | .0 | .0 | .0 | .0 | .0 | .16562E-01 | .978253 |
| 105 | 349.28 | 14.700 | .48593E-01 | .93741E-02 | .0 | .10931E-02 | .15469E-01 | .0 | .0 | .0 | .0 | .978251 |
| 106 | 349.28 | 14.700 | .48593E-01 | .93741E-02 | .0 | .10931E-02 | .15469E-01 | .0 | .0 | .0 | .0 | .978251 |
| 107 | 353.48 | 14.700 | .15905E-01 | .93741E-02 | .0 | .10931E-02 | .15469E-01 | .0 | .0 | .0 | .0 | .912351 |
| 108 | 353.49 | 14.700 | .15905E-01 | .93741E-02 | .0 | .10931E-02 | .15469E-01 | .0 | .0 | .0 | .0 | .912352 |
| | 3 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| | 4 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 21 | 353.48 | 14.696 | .0 | 1.4065 | .0 | .0 | .0 | 1.5440 | 6.2113 | .77999E-01 | .0 | 251.878 |
| | 353.48 | 14.696 | .0 | 1.4065 | .0 | .0 | .0 | 1.5440 | 6.2113 | .77999E-01 | .0 | 251.878 |
| | 5 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 5 | 326.34 | 14.696 | .0 | 1.4623 | .0 | .0 | .0 | 1.6575 | 6.6016 | .82904E-01 | .0 | 267.652 |
| 7 | 340.80 | 14.696 | .0 | 1.4623 | .0 | .0 | .0 | 1.6575 | 6.6016 | .82904E-01 | .0 | 267.652 |
| 8 | 353.48 | 14.696 | .0 | 1.4950 | .0 | .0 | .0 | 1.6411 | 6.6016 | .82904E-01 | .0 | 267.717 |
| 9 | 353.48 | 14.696 | .0 | 1.4950 | .0 | .0 | .0 | 1.6411 | 6.6016 | .82904E-01 | .0 | 267.717 |
| 10 | 353.48 | 14.696 | .0 | .88476E-01 | .0 | .0 | .0 | .97124E-01 | .39071 | .49064E-02 | .0 | 15.8440 |
| 11 | 353.48 | 14.696 | .0 | .88476E-01 | .0 | .0 | .0 | .97124E-01 | .39071 | .49064E-02 | .0 | 15.8441 |
| | 6 TF | PT | MH2 | MH2O | MCH4 | MCO | MCO2 | MO2 | MN2 | MA | FUEL | PPH |
| 20 | 353.48 | 14.696 | .0 | 1.4065 | .0 | .0 | .0 | 1.5440 | 6.2111 | .77998E-01 | .0 | 251.873 |
| | 353.48 | 14.696 | .0 | 1.4065 | .0 | .0 | .0 | 1.5440 | 6.2111 | .77998E-01 | .0 | 251.874 |

NET AC POWER = 0. WATTS

HEATER POWER = 300.0 WATTS

INVERTER EFFICIENCY = 84.0 %

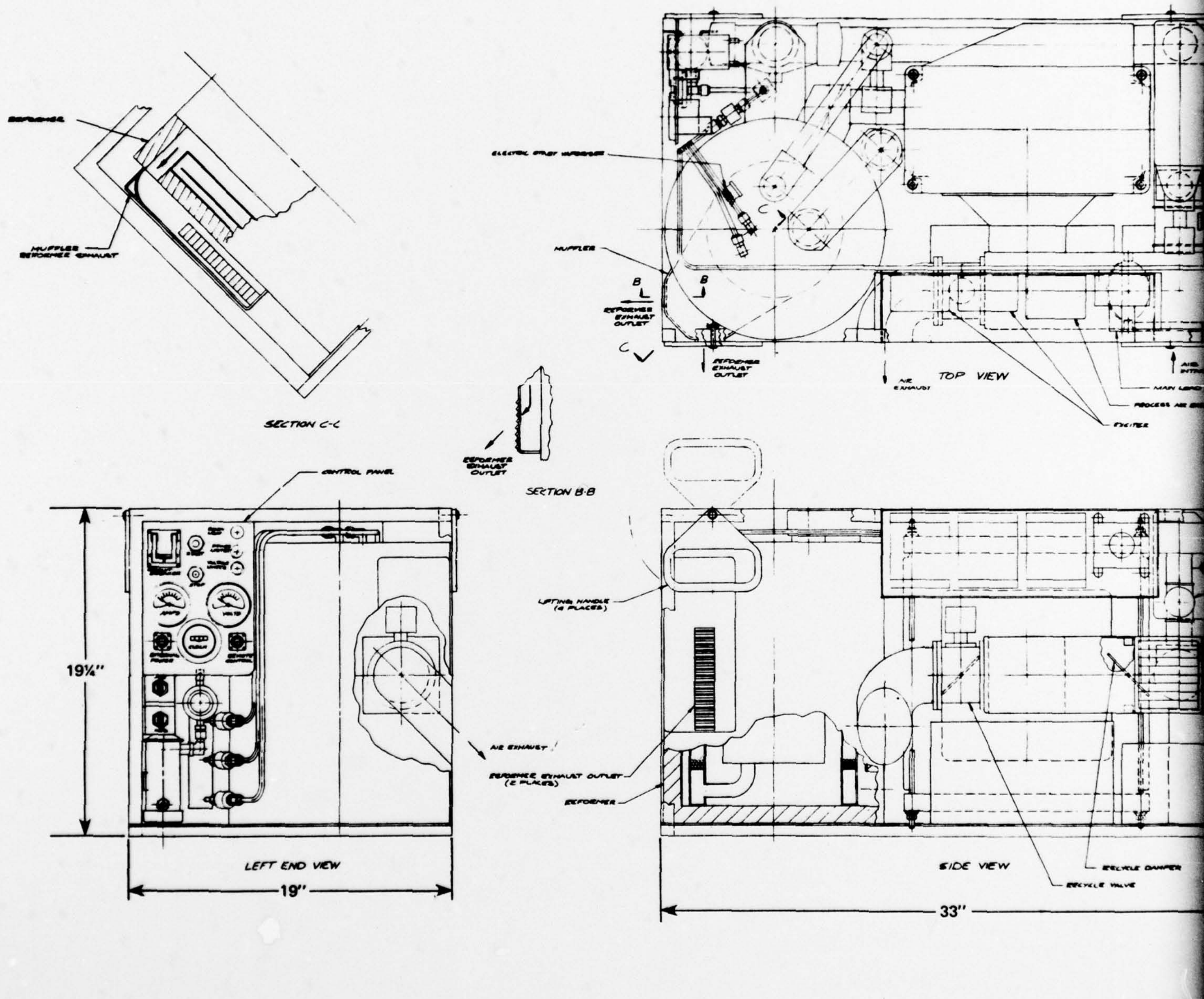
TAMB 125.0 °F

POWERSECTION CURRENT = 9.9 AMPS

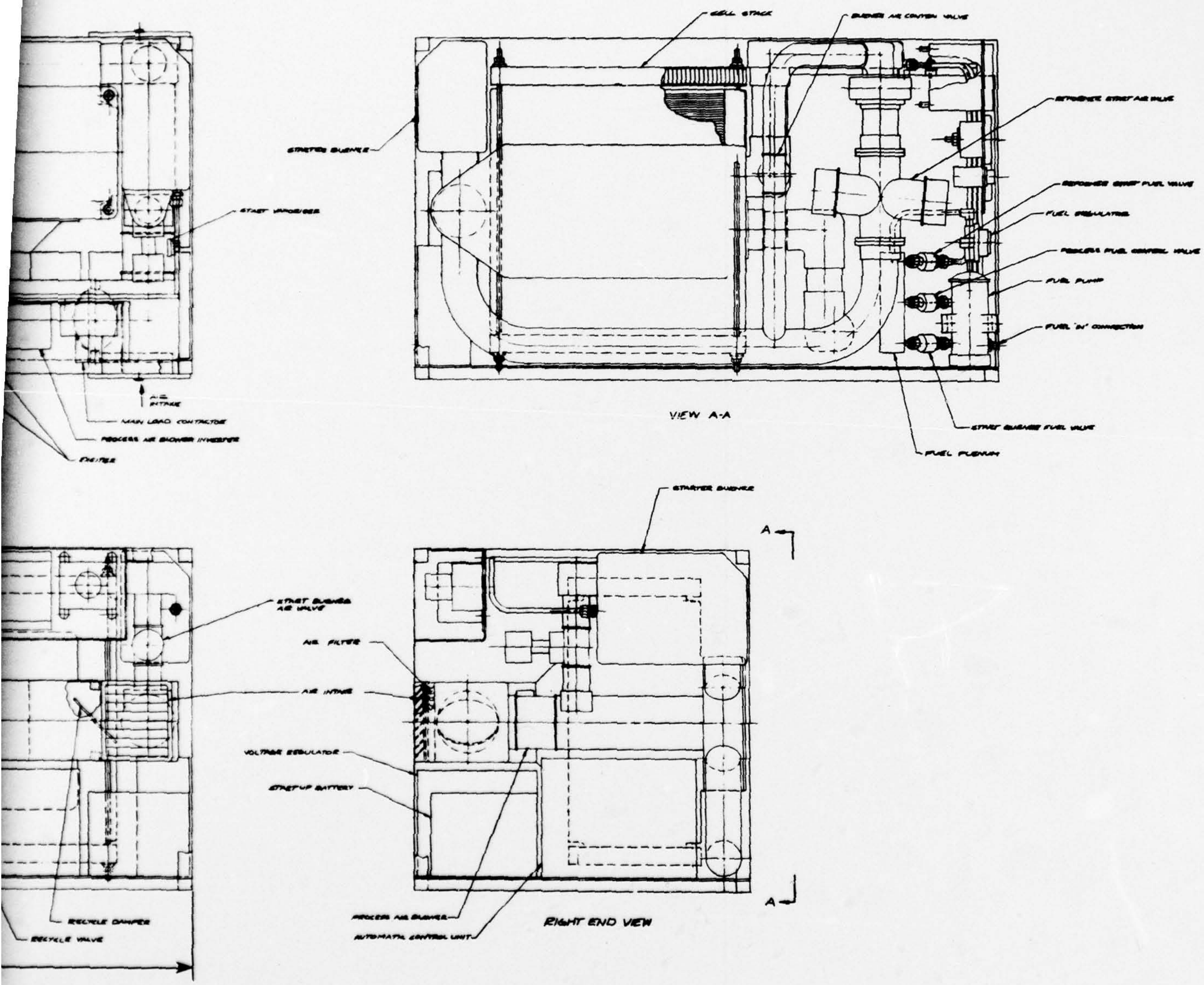
DC VOLTAGE = 58.12 VOLTS

SPECIFIC FUEL CONSUMPTION = NOT APPLICABLE

RELATIVE HUMIDITY: 95.0 % CELL PERFORMANCE 6000 HR


REFORMER
MUFFLER
REFORMER EXHAUST
SECTION C-C
MUFFLER
REFORMER EXHAUST OUTLET
TOP VIEW
AIR EXHAUST
EXCITER
REFORMER EXHAUST OUTLET
SECTION B-B
CONTROL PANEL
19¼"
LEFT END VIEW
19"
AIR EXHAUST
LIFTING HANDLE (4 PLACES)
REFORMER EXHAUST OUTLET (2 PLACES)
REFORMER
SIDE VIEW
RECYCLE DAMPER
RECYCLE VALVE
33"

1




VIEW A-A

RIGHT END VIEW